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A Monthly Journal devoted to the Arts and Sciences Related to the Silicate Industries

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JOURNAL
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EDITORIALS

TECHNOLOGIC MONOGRAPHS

The American Chemical Society is about to issue a series of technologic monographs. Each monograph is to cover one phase of chemical technology. The following description of what the board of editors of the proposed series consider a good monograph is of interest:

"The ideal monograph is a critical presentation of the topic which it treats, and gives the reader the present status of the knowledge of that topic in such a way that he need not consult prior literature except for details: it should show clearly which points are still uncertain and require further investigation and so act as an incentive to research by suggesting problems. The preparation of such a monograph implies that the author has first-hand knowledge of the topic treated and this implies in turn, particularly in the case of technologic monographs, that the topic chosen must not be too large. In other words, i ntead of a book dealing with a very broad general topic, we would prefer a number of more specific smaller topics, each written by a man thoroughly conversant with that particular phase. The board wishes to emphasize that the proposed series will aim to be critical in character, rather than mere compilations; and takes this ground because a number of existing monographs cover a field broader than the author was really familiar with, the result being that the book contains one or two good chapters but is largely a somewhat uncritical compilation of material."

There is need for a similar series of publications in the ceramic industries. It might be well for those intending to prepare monographs for these industries to study carefully the foregoing description. Some of the monographs on ceramic subjects issued in the past certainly have not complied with this.

A COMPENDIUM OF CHEMICAL AND PHYSICAL CONSTANTS

At a meeting of the Inter-Allied Chemical Conference held in London, July 14–17, 1919, there was formed an International Union of Pure and Applied Chemistry, and it was voted that "Critical tables of physical and chemical constants shall be published in the United States and there shall be created an American publication committee charged with the general organization and the prosecution of the work." It is proposed to issue a critical compendium of chemical and physical constants, which shall be up to date and correct; and which shall contain such new constants as can be determined before the time of publication as well as many which have been determined but which are not now generally available. This work has been undertaken by the National Research Council in coöperation with the American Chemical and the American Physical Society. The business arrangements are to be in the hands of a board of three trustees: Mr. Hugh K. Moore, chairman (appointed by the National Research Council); Mr. Julius Stieglitz, (appointed by the American Chemical Society); and Mr. Edward P. Hyde (appointed by the American Physical Society).

AMERICAN ENGINEERING STANDARDS COMMITTEE

After almost three years of painstaking investigation and discussion by the engineering fraternity the revised constitution of the American Engineering Standards Committee, along with the by-laws and rules of procedure, has been adopted, and has been ratified by the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers, and the American Society for Testing Ma-

terials, and the three Government Departments of Commerce, Navy and War. Each of these interests have three representatives, and although the Committee as it exists today consists of twenty-four members, the new Committee is of very wide scope and allows the direct or indirect participation of anyone interested in standardization.

The American Engineering Standards Committee makes it possible to give an international status to approved American engineering standards and to coöperate with similar organizations in other countries. Similar organizations are now functioning in Great Britain, France, Switzerland, Holland and Canada.

Through the new Committee the methods of arriving at engineering standards will be unified and simplified and, by coöperation, the duplication of standardization work will be prevented. Standards will not be created without giving all interested an opportunity to participate.

Any organization may request the Committee to approve standards which it has formulated, or to approve committees that it has appointed, and by so doing becomes a sponsor society. Two or more organizations may act as joint sponsors. Approval of a standard is given when it is the substantially unanimous conclusion of a section committee made up of representatives of producers, consumers and general interests, and so selected that all interests concerned have adequate representation on the section committee.

The "approval" of a standard by the American Engineering Standards Committee does not mean that the Committee has itself worked over and approved each detail, but rather that the work has been carried out by a sectional committee adequately representing the industry concerned, and sponsored by one or more bodies of ability, experience and standing, so that the result may stand for what is best in American engineering practice.

ORIGINAL PAPERS AND DISCUSSIONS

ADDRESS OF THE RETIRING PRESIDENT

THE NEED OF TECHNICAL ASSISTANCE IN THE BRICK INDUSTRY

By R. T. Stull

Considerable progress has been made in the clay industry within the last half century but it has not maintained the pace with progress made in many other industries. The plea for the need of research in glass by Dr. Washburn and that of Mr. Purdy for research in refractories appearing in the November issue of the Journal, are both excellent and timely. However, an analysis of the situation reveals the fact that the same urgent need for research exists in practically all other ceramic industries and more especially does this need exist in the clay industries.

The value of all ceraime products[1] in round numbers amounts to $500,000,000 per annum. Of this sum approximately $250,000,000, or one-half, is represented by clay products. The value of brick of all kinds, including common, face, paving, ornamental, enamel and fire-brick is placed at approximately $120,000,000. The value of brick, therefore, represents about 24 per cent of the value of all ceramic products and 48 per cent of all clay products. Brick represent the largest item in value of all the different ceramic products.

The industry is composed of a large number of comparatively small units and the number of plants representing the investment

[1] The value of all ceramic products is given as $447,000,000 in *J. Am. Ceram. Soc.*, 1, 372. The value of all clay products reported in "Clay-working Industries and Building Operations in the Larger Cities in 1917" by Jefferson Middleton, U. S. G. S., is given as $248,023,368 and the value of brick of all kinds gives a total of $118,076,507.

of a million dollars or more can be counted on the fingers of one hand.

The date when brick making began is unknown and the industry has played an important part in history throughout the ages down to the present time. At present the industry is carried on in every state of the Union and in our foreign possessions. From the points of value, extent and distribution of the industry, brick are bound to exercise no small influence upon the economic life of mankind.

Approximately 70 per cent of the cost of production of brick is about equally divided between fuel and labor; an extravagant use of these two commodities such as no other industry would very long tolerate.

Advancements have been made but these advancements have been confined principally to both ends of the process while the middle has been marking time. At the beginning of the processes, mining the clay by steam shovel or planer, its transportation, grinding, screening and pugging are practically automatic. At the finishing end the continuous and tunnel kilns have made it possible to save from 40 to 70 per cent of the fuel as compared to the intermittent kiln. However, from the cutting table on through the process until the brick are delivered to the stock piles, the movement of material is almost entirely dependent upon hand labor.

There is no end to the problems needing investigation in order to learn the "how" and "why" but that most needed in the brick industry today is "mechanical assistance."

After the brick leave the cutter they are hacked by hand on dryer cars. When dry they are taken from the dryer cars and set in benches in the kiln. After the firing process has been completed and the brick cooled, they are taken from the benches, sorted and hacked on wheelbarrows or trucks. The brick are conveyed to the stock pile or freight car and again handled for the fourth time.

The first auger machine was made over fifty years ago and up until a few years ago it was stated that this same machine was still making brick. The auger moulding machines, built since the appearance of the pioneer have been constructed along the same

lines of their predecessor. The improvements over their forerunner have been confined principally to increase in size, strength and capacity and have been constructed along lines of better proportions, but the fundamental principles of auger knives and barrel have remained unchanged.

Approximately 60 per cent of the power applied to the moulding machine is lost in friction and resistance of the auger and knives in cutting through the clay or churning it around in the barrel and as long as we are dependent upon an auger for forcing the clay through a die, just so long will it be necessary to contend with laminations.

It is not impossible to develop a moulding machine in which all the power expended is utilized in moulding the clay column except that necessarily lost in the friction of the bearings, and which can mould a clay column substantially free from laminations. If such a machine can be developed it must necessarily be a radical departure from the present auger machine.

The two principal requirements that a shale or clay must possess in order to make a successful paving brick are long vitrification range and ability to make brick which will meet the requirements of the rattler test. There are a large number of clays and shales of long vitrification range but which laminate so badly when moulded on the auger machine that they will not withstand the rattler test. The development of a moulding machine capable of moulding a clay column substantially free from laminations would broaden the manufacture and uses of paving brick and develop the industry in localities now remote from good paving brick clays. It would also make possible the moulding of stiff mud fire-brick of better structure.

The moulding, drying and firing of brick are simple operations as compared to more complicated things done by automatic machinery in other industries. It is true that automatic setting machines are in successful operation, setting brick in scove or open top kilns, but a successful machine for closed kilns remains to be developed. Numerous patents have been issued on automatic hacking machines, but their practical worth is still a question, since they have not been put into practical operation. A brick plant was built several years ago to eliminate hand labor,

but the success of this plant has evidently not been considered sufficient to warrant the building of other plants along the same lines.

All these experiments and investions are commendable and good in that they are the necessray pioneers in the course of development. The first automobiles were unreliable as to movement, since they might run a few miles or only a few feet and stop without apparent cause and require a half day's tinkering before they would start again. But they were the pioneers representing progressive steps leading to the almost perfectly operating automobiles of today.

The time will come when brick will be made automatically without being touched by human hands throughout the process of manufacture. It will require years of painstaking experimental work and require the expenditure of many thousands of dollars.

The modern bottle blowing machine has done more to advance the glass bottle industry than any other single achievement. Its development required a number of years and the expenditure of over half a million dollars. Its development, however, was made possible by the widsom and foresight of a capitalist who was willing to furnish the necessary financial backing. There is no brick manufacturing corporation large enough or willing to "tie up" the necessary capital over the period of years required in perfecting the automatically operated brick plant.

The modern automobile is a wonderful machine made up of a number of intricate parts. It is not the invention of one man but represents the best thoughts and efforts of hundreds of men, each contributing his part to the many intricate details woven together into a harmoniously operating machine. Thus it will be with the automatically operated brick plant of the future. It will not represent the inventive talent of one or two men but the best efforts of many mechanical, electrical and ceramic engineers and practical brick makers.

When a number of inventors are working independently and more or less secretly in developing certain mechanical phases of an intricate process, it means more or less duplication of work and requires a long period of time before these inventions can be sifted and the best features brought together and formed into a synchronized and practically working unit. Such development also

involves patent conflicts and delays in securing control of certain desirable patented features.

The retail price of brick has nearly trebled in the last ten years and the bulk of this increase in price is due to the increased cost of fuel and labor. Very little has been done in the last decade to reduce the cost of these two items and that which has been done has not been fully taken advantage of by the brick industries.

If the retail prices of brick are to be appreciably reduced and still leave a fair margin of profit to the manufacturer, it is obvious that the cost of production must also be reduced. Since 70 per cent of the cost of production is chargeable to fuel and labor, reduction in the cost of production must be made largely in the cost of these two items. The only solution to the problem appears to be the development of automatic machinery and the improvement of the continuous or the tunnel kiln.

The evolution of the industry, if left to itself, will be slow and the total sum expended will represent a huge sum. In the meantime the market price of brick must be governed largely by the conditions of fuel and labor.

There seems to be one of two possibilities by which the problem may be solved efficiently, economically and in the shortest possible time. First, that the enterprise be financed by a capitalist or corporation not afflicted with "cold feet" or impatience and willing to finance the enterprise to the limit. Second, the formation of a development corporation composed of a large number of brick companies and sufficiently capitalized to meet the necessary experimental requirements. A plant should be set aside as an experimental plant or, what would perhaps be better, to build an experimental plant on a sufficiently large scale to work out the process in a practical way.

In planning such an enterprise, we must not lose sight of the value of research of the physico-chemical nature. The experimental plant and the research laboratory should be combined, for many problems will arise of the "how" and "why" nature which must be solved in the laboratory. The big problem is that involving mechanics, but when the "modern brick plant of the future" is finally evolved, it will be found that no small part will have been contributed by the research laboratory.

MAGNESITE REFRACTORIES

By J. Spotts McDowell[1] and Raymond M. Howe[2]

Authors' Note

The technical press of the past generation contains a large number of papers dealing with refractory magnesite, scattered throughout various periodicals. While these are of great value, many of them are not readily available to the average reader, and their range is in most cases narrow. There is not a single treatise in which the subject has been treated as a whole from a modern point of view.

In compiling the material herein presented, the authors have endeavored to survey the salient facts in the entire field pertaining to the occurrence, preparation and properties of magnesite for refractory use. Most of this material has been taken from the available technical literature, which has been drawn upon for whatever was considered to be of permanent value or of particular interest at the present time. Abundant references in footnotes, and a bibliography are included. Acknowledgment is due the Research Laboratories of the Harbison-Walker Refractories Co. and of the Mellon Institute of Industrial Research for such data as are here published for the first time. The authors wish to express thanks to Kenneth Seaver, Dr. E. W. Tillotson, R. D. Pike, W. F. Rochow and Dr. C. R. Fettke for their critical review of the manuscript.

Introduction

The mineral magnesite enters into the preparation of a variety of products. Its chief use is in the manufacture of refractory materials, since its chemical properties and high refractoriness render it particularly suitable as furnace linings for various metal-

[1] Research Department, Harbison-Walker Refractories Co., Pittsburgh, Pa.

[2] Refractories Manufacturers Association Fellowship, Mellon Institute of Industrial Research, Pittsburgh, Pa.

lurgical operations. For refractory purposes it is sold in the form of brick, of finely ground "furnace magnesite" for brick laying, and of dead-burned grains for making and repairing furnace bottoms. The grains are a mixture of granules varying in size from pieces of about $^5/_8$ inch in diameter to very fine but gritty particles.

While magnesite is an important refractory in the metallurgy of copper, lead and nickel, and for electric, heating and welding furnaces in the steel industry, its principal application is in the basic open-hearth steel furnace. The hearth of the furnace, according to well-established American practice, is usually built up of magnesia brick and dead-burned grain magnesite, so laid that the brick base is protected by a working bottom of the granular material. The latter, mixed with 10 to 15 per cent of granulated open-hearth furnace slag, is sintered into place in layers $^1/_2$ to 1 inch thick to a total depth of 12 to 18 inches at the center of the furnace.

Magnesite enters also into the production of the following materials: Oxychloride or Sorel cement, from which exterior stucco, flooring, and other structural materials are made; fireproof paint; CO_2 gas; metallic magnesium; magnesium chloride; magnesium sulphate (Epsom salt); basic carbonate of magnesia, used as a heat insulator for boilers, pipes and so forth, as a toilet preparation, and for various other purposes; wood pulp for the sulphite process; minor miscellaneous products.

PART I. HISTORICAL NOTE ON THE DEVELOPMENT OF MAGNESIA REFRACTORIES IN STEEL MAKING

While the widespread adoption of magnesia as a furnace refractory is a development of the last generation, considerable experimental work had been done much earlier. As early as 1860 when the Bessemer process was being introduced in Europe, Tunner of Leoben, Austria, suggested the use of calcined magnesite for converter linings, although his suggestion had nothing to do with the dephosphorizing of steel.[1] In 1864 A. Frank prepared magnesia from magnesium chloride solution and made

[1] Harbord and Hall, "Metallurgy of Steel," published by J. B. Lippincott Co., 1916, p. 58.

brick therefrom, which was employed in the bridge-wall of a furnace. The practice was soon given up because there was no demand for such brick.[1]

According to a paper published in 1867 by A. Schwartz, magnesia brick was being used at that time in Donawitz near Loeben, Austria, in puddle furnaces and for other refractory purposes. The bricks were made by mixing ground magnesite with a small amount of refractory clay and burning at a rather high temperature. They gave good service in the bridge-wall of the puddle furnace. At ordinary temperatures they had to be carefully protected from moisture, since their high lime content caused slaking.

Caron,[2] in France, had made experiments to determine the practicability of adopting magnesia in the making of crucibles and refractory brick, and for lining reverberatory steel-melting furnaces, and in 1868 published a paper on the subject.[3] The material used in his experiments was the amorphous magnesite from the Greek Island of Euboea. He succeeded in making brick by mixing one part of lightly calcined magnesite, as a bond, with six parts which had been calcined at white heat, moistening the mixture with 10 to 15 per cent of water, and molding under a very high pressure. He also made small magnesia crucibles and found that they could be exposed to the air for a long time without injury. The value of the light-burned magnesite as a bond resulted from its property of setting and hardening when moistened with water and later dried.

About 1870 the attempt was made in England to melt steel in small magnesia crucibles, but without success. The crucibles stood the heat well so long as they were kept empty and in the furnace, but fell to pieces when taken out of the fire. Three or four years later Muller & Co., near Paris, made some magnesia linings intended for service in the Bessemer converters of the Creusot Steel Works, and suggested the adoption of magnesia in

[1] Robert Sherer, "Der Magnesite," published by A. Hartleben, 1908, p. 83.

[2] Jno. Percy, "Metallurgy," published by Murray, London, 1875, p. 135.

[3] *Compt. rend.*, **66**, 839 (1868).

the hearth of the Siemens furnace. The suggestion seems to have been carried out, for at the meeting of the Iron and Steel Institute in May 1879, C. W. Siemens announced[1] that several years earlier he had employed magnesia brick in an open-hearth furnace. He considered it a splendid lining, but found it very expensive and had given it up because the slag acted on it more rapidly than was desirable.

The discovery of Thomas and Gilchrist, made public in 1879,[2] that phosphorus can be eliminated from steel by proper treatment in a basic lined vessel, focussed the attention of steel men upon the great need for a satisfactory basic refractory, and led to numerous independent investigations. The first basic Bessemer and basic open-hearth furnaces were lined with dolomite; and although it was soon found to possess serious defects as a refractory material, its use to a minor extent has continued to the present day. It was employed in the calcined condition for hearth linings and for the manufacture of brick by bonding with tar.

In the early eighties considerable work was done in Germany in the attempt to produce satisfactory magnesia linings, and in the spring of 1882 magnesia brick was being offered for sale in that country.[3] About that time German bricks were being made from magnesia artificially prepared from dolomite; difficulties were encountered, however, on account of its lack of bonding power, and the brick was too expensive to compete with the dolomite-tar brick.[4] Experiments with dead-burned Grecian magnesite grains for furnace bottoms also gave unsatisfactory results. The material utilized was too refractory to sinter together properly at furnace temperatures, and patches of the bottom often came up and floated in the bath.[5] When a sufficient amount of

[1] *J. Iron Steel Inst.*, **14–15,** 153 (1879).

[2] Thomas and Gilchrist, "On the Removal of Phosphorus," *Ibid.*, **14–15,** 120 (1879). Geo. W. Maynard, "The Introduction of the Thomas Basic Steel Process in the U. S.," *Trans. Am. Inst. Mining Eng.*, **41,** 280 (1910).

[3] *Stahl u. Eisen*, May, 1882, advertisement.

[4] T. Egleston, "Basic Refractory Materials," *Trans. Am. Inst. Mining Eng.*, **14,** 455 (1885–6).

[5] "Magnesia and Dolomite as Basic Refractory Materials," *J. Iron Steel Inst.*, **28–29,** 894 (1886).

such material as clay was added to form a strong bond, the refractoriness was greatly lowered. These difficulties were overcome when it was found that a crystalline magnesite from Styria, by reason of its high content of iron, had the property of sintering into a hard, dense mass without fusion.[1] This material when dead-burned, could be manufactured into dense, strong brick of high refractoriness, and used for the construction of open-hearth furnace bottoms which were highly resistant to the erosion of molten metal and the action of slags. The Styrian magnesite by 1887 had almost completely displaced all others for lining furnace bottoms, and until early in the late war maintained this supremacy. In the late eighties, the use of grain magnesite in place of dolomite for open-hearth furnace bottoms increased rapidly in continental Europe,[2] although dolomite continued to be employed at a great many plants, particularly in England. It has been stated that in 1888, fifty pounds of magnesia or 150 pounds of dolomite were required per ton of steel produced.

Imports of magnesite into the United States began in 1885 with a shipment of 800 tons of crude Austrian (Styrian) magnesite brought in by the Otis Steel Company, who made use of it in the following year at their plant in Cleveland in the first basic open-hearth experiments made in America. After dead burning the magnesite, it was utilized to line a 15-ton open-hearth furnace previously operated as an acid furnace; the bottom was built up by ramming a mixture of dead-burned magnesite and tar into place. The experiment was not a commercial success, and the use of magnesite was given up.[3]

Carnegie, Phipps & Co. began the successful manufacture of basic open-hearth steel at Homestead in 1888. Early in that year the following prices per gross ton were quoted for magnesite delivered at New York: Brick $38.00; dead-burned magnesite $16.00; crude magnesite $9.00.[4] Large importations did not

[1] K. Sorge, "Magnesia and Its Use as a Basic Refractory," *Stahl u. Eisen*, **7**, 850 (1887).

[2] "The Use of Magnesite for Basic Linings," *J. Iron Steel Inst.*, **43**, 315 (1890); "Magnesite in Open-Hearth Linings," *Stahl u. Eisen*, **10**, 222 (1890).

[3] G. W. Maynard, "Introduction of Basic Open Hearth Steel in the United States," *Trans. Am. Inst. Mining Eng.*, **41**, 289 (1910).

[4] A. E. Hunt, "Recent Improvements in Open Hearth Steel Practice," *Ibid.*, **16**, 718 (1887–1888).

begin until 1898, when 16,000 tons were brought in. Since that time, with the rapid increase of basic open-hearth steel production in this county, the use of magnesite as a refractory has greatly increased, and the United States now consumes about 70 per cent of the world's output. In the years immediately prior to the war over 90 per cent of the magnesite consumed in the United States came from Austria, being imported in the form of dead-burned "grains." This material was employed for the manufacture of brick, and also, without further treatment, for the construction of open-hearth furnace bottoms.

To meet the shortage brought about by the cessation of shipping from Austria early in the war, magnesite was imported from Greece and Canada, domestic deposits were developed, and dolomite was substituted for magnesite wherever practicable. The deposits of this country are now developed sufficiently so that an adequate present supply is available, and ample reserves are in sight to last many years. The following table shows the amount of magnesite produced in the United States and imported since 1911, and the great expansion of domestic production since 1914.

TOTAL MAGNESITE CONSUMPTION OF UNITED STATES ON A CALCINED BASIS

	Net tons			Tonnages reduced to calcined basis assuming 2.1 T. crude = 1 T. calcined		
	Domestic[a]	Imported[a]				
Year	Crude	Crude	Calcined	Domestic	Imported	Total
1911.....	9,375	12,974	122,075	4,463	128,253	132,716
1912.....	10,512	17,905	125,252	5,006	133,778	138,784
1913.....	9,632	13,235	167,094	4,587	173,396	177,983
1914.....	11,293	13,354	121,817	5,378	128,176	133,554
1915.....	30,499	49,764	26,574	14,423	50,271	64,794
1916.....	154,974	75,345	9,270	73,797	45,148	118,945
1917.....	316,838	30,277	3,966	150,875	18,384	169,259
1918.....	231,605	5,432	19,049	110,228	21,636	131,924

[a] Figures taken from reports of United States Geological Survey.

At the beginning of the war, the refractories manufacturers were crippled by a lack of calcining facilities, since the Austrian material had been imported in the calcined condition; the low iron content of the available magnesite caused additional difficulties. In order to confer the proper sintering and bonding properties, it became necessary to add iron oxide and to incor-

porate it thoroughly by burning at an extremely high temperature. Magnesite thus treated, when sufficiently low in harmful impurities, is a high-grade refractory and gives entirely satisfactory service.

PART II. CRUDE MAGNESITE[1]

Mineralogy.—The mineral magnesite, when pure, is composed of 47.6 per cent magnesia and 52.4 per cent carbon dioxide. It is one of the calcite group of rhombohedral carbonates, which closely resemble each other in crystalline structure, symmetry and cleavage. The members of this group of interest in this connection are the following:

Mineral	Formula	Specific gravity	Theoretical analyses			
			MgO	CaO	FeO	CO_2
Calcite	$CaCO_3$	2.72	..	56.0	..	44.0
Dolomite	$CaCO_3 \cdot MgCO_3$(*a*)	2.85	21.7	30.4	..	47.8
Magnesite	$MgCO_3$	2.90–3.08	47.6	..	..	52.4
Magnesite, var. breunnerite(*b*)	$Mg(Fe)CO_3$	3.08–3.20	..	..	..	..
Mesitite	$2MgCO_3 \cdot FeCO_3$	3.35–3.36	28.2	..	25.3	46.5
Pistomesite	$MgCO_3 \cdot FeCO_3$	3.42	20.0	..	36.0	44.0
Siderite	$FeCO_3$	3.83–3.88	..	..	62.1	37.9
Ankerite(*c*)	$CaCO_3 \cdot (MgFe)CO_3$	2.95–3.10	10.0	28.0	18.0	44.0

(*a*) Normal dolomite. Varieties occur in which the ratio of the two carbonates is not 1:1.

(*b*) Composition variable.

(*c*) Composition variable—analysis given is for normal ankerite.

Other related minerals, not of the same crystallographic group, are:

Mineral	Formula	Specific gravity	Analysis		
			MgO	CO_2	H_2O
Hydromagnesite	$3MgCO_3 \cdot Mg(OH)_2 + 3H_2O$	2.15–2.18	43.9	36.3	19.8
Brucite	$Mg(OH)_2$	2.38–2.40	69.0	..	31.0

Magnesite does not form an isomorphous series with calcite or dolomite; consequently, when it contains calcium carbonate

[1] L. C. Morganroth, "The Occurrence, Preparation and Use of Magnesite," *Trans. Am. Inst. Mining Eng.*, **50**, 890 (1914); Thomas Crook, "Magnesite as Raw Material," *Trans. Ceram. Soc. (Eng.)*, **18**, 67 (1918–19). This paper describes all the well known magnesite deposits of the world.

the latter is present as included grains of dolomite, which can often be removed by mechanical processes. Magnesium and iron carbonates, however, form a continuous isomorphous series, and the variety of magnesite known as breunnerite is an isomorphous mixture of the two containing a variable percentage of iron carbonate. Crook[1] has suggested that when the iron carbonate content is less than 5 per cent the mineral should be termed magnesite, and that the term breunnerite be used when the iron carbonate content is between 5 and 30 per cent.

Two types of magnesite are to be distinguished; the crystalline and the dense or cryptocrystalline. The former, which includes breunnerite, is often termed spathic magnesite. It varies from finely to coarsely crystalline in texture, and has a hardness of $3^1/_2$ to 4; it is easily broken up and ground, especially when of coarse texture. The color is white, yellowish, blue-gray to drab, red, pink, black or mottled. It is seldom found pure, but usually contains slight admixtures of iron, lime, silica and sometimes a small amount of manganese. The color cannot be used as an index of the purity; colored magnesites of Washington, for example, are often very pure.

The cryptocrystalline variety, usually spoken of as amorphous magnesite, is the more common type. It is fine grained and compact, showing no cleavage. In color it is usually snow-white, but is sometimes light to pale orange-yellow or buff, due to the presence of impurities. The fracture is conchoidal to uneven, and the hardness $3^1/_2$ to 5. The presence of several per cent of silica, caused by inclusions of serpentine, quartz, chalcedony, opal, and so forth, is not uncommon. The lime and iron contents are usually low, although a few deposits are known in which the $FeCO_3$ content is as high as 4 per cent. In general, amorphous magnesite is somewhat purer than the crystalline variety.

The specific gravity of the dense variety of magnesite is 2.90 to 3.00, averaging about 2.94 when pure. Cleavage fragments of pure crystalline magnesite have a specific gravity of 3.02; values of 3.08 or higher indicate the presence of ferrous carbonate. The average specific gravity of breunnerite is 3.08 to 3.13.

[1] Thomas Crook, *op. cit.*, p. 75.

Dissociation of Mineral Carbonates.—When heated to a high degree a gradual decomposition of the carbonate minerals takes place, with the evolution of CO_2. At any given temperature each mineral has a definite dissociation pressure, which increases with the intensity of the heat. The temperature at which it becomes equal to 760 millimeters of mercury, or one atmosphere, is known as the dissociation point. Decomposition of the minerals begins and under proper conditions can be carried to completion at a much lower heat than this, if the CO_2 evolved is carried off. However, in the calcination of such minerals as magnesite under industrial conditions, a considerably higher temperature than the dissociation point is required to remove all the CO_2. The temperature necessary is dependent upon the size of the lumps, the texture of the mineral, the amount and character of impurities, and the duration of the heating.

Montgomery and Groves[1] found that on heating pure precipitated $CaCO_3$ a loss in weight of 2.35 per cent per hour occurred at 620–627° C, of 4 per cent per hour at 647° C, and that after 15 hours at 647° C the CO_2 was completely driven off. The dissociation point of calcium carbonate[2] has been given by different observers as 880° C (limestone),[3] 886° C,[4] 898° C,[5] 910° C[6] and 913–923° C.[7] Johnston's determination of 898° C is probably the most accurate. His figures for the dissociation pressures of $CaCO_3$ in millimeters of mercury are given below:

[1] Montgomery and Groves, "Note on Determination of Several Dissociation Points," *Trans. Am. Ceram. Soc.*, **18,** 214 (1916).

[2] E. H. Riesenfeld, "The Decomposition of Carbonate of Lime," *J. Chim. Phys.*, **7,** 561 (1908); *Chem. Abstracts*, **4,** 982 (1910).

[3] Bleininger and Emley, "The Burning Temperature of Limestones," *Trans. Am. Ceram. Soc.*, **13,** 618 (1911).

[4] De Forcrand, "Carbonates of the Alkalis and Alkali-earths," *Compt. rend.*, **146,** 511 (1908).

[5] John Johnston, "The Thermal Dissociation of Calcium Carbonate," *J. Am. Chem. Soc.*, **32,** 938 (1910).

[6] D. Zavreiff, "The Dissociation of Calcium Carbonate," *Compt. rend.*, **145,** 428 (1907); *J. Chim. Phys.*, **7,** 31 (1908); *Chem. Abstracts*, **3,** 1112 (1909).

[7] J. A. Hedvall, "Formation and Decomposition Temperatures of the Carbonates of Strontium, Barium, Calcium and Magnesium," *Z. anorg. allgem. Chem.*, **98,** 147 (1916).

°C	Pressure	°C	Pressure
500	0.11	850	373.0
600	2.35	898	760.0
700	25.3	900	773.0
750	68.0	950	1490.0
800	168.0	1000	2710.0

Working with materials carefully prepared and purified by precipitation, O. Brill[1] found that magnesium carbonate begins to dissociate at 237° C under a pressure of one atmosphere of CO_2; evolution of CO_2 takes place in steps, forming a series of basic carbonates with different dissociation temperatures. The final member of this series, $7MgO.CO_3$, dissociates completely at 510° C. These results are not comparable with determinations made on the natural mineral magnesite.

According to Hedvall[2] the dissociation pressure of magnesite reaches one atmosphere at 531–570° C. Wülfing[3] found that in a furnace kept at a constant temperature of 500° C magnesite lost less than half its CO_2 in two hours, and that not all the CO_2 had been driven off in 12 hours. Kallauner[4] reports that amorphous magnesite begins to dissociate at about 500° C, and that CO_2 is evolved very rapidly at 620° to 625° C. He finds also that the dissociation of normal dolomite begins at 500° C, increases rapidly with rising temperature and reaches a maximum between 710° and 730° C; from 730° to 870° C dissociation is slow, but it increases above 870° C and reaches another maximum at 900° to 915° C. CaO did not appear in the heated material below 875° C. It was believed that the dolomite, $MgCO_3 \cdot CaCO_3$, began to separate into its components $MgCO_3$ and $CaCO_3$ at about 500° C, that the $MgCO_3$ formed dissociated rapidly at 710°–730° C and that dissociation of the $CaCO_3$ began at 870° C.

The dissociation temperature of siderite is 100° to 150° C

[1] O. Brill, "The Dissociation of the Carbonates of the Alkaline Earths and Magnesium," *Z. anorg. Chem.*, **45**, 275 (1905).

[2] *Op. cit.*

[3] E. Wülfing, 1900, as quoted in Doelter's "Handbuch der Mineral Chemie," **1**, 231.

[4] O. Kallauner, "Thermal Dissociation of Amorphous Magnesite," *Chem. Ztg.*, **37**, 182 (1913); "Thermal Dissociation of Normal Dolomite," *Chem. Ztg.*, **37**, 1317 (1913).

lower than that of magnesite. It is not unlikely that this fact has a favorable effect in the calcination of the Austrian breunnerite.

Crystalline Magnesite.—Crystalline magnesite occurs in much larger deposits than does the compact type and hence can usually be produced more cheaply. The texture of breunnerite is much coarser than that of spathic magnesite low in iron, much of which has an even, granular, sugary texture, resembling calcite and dolomite. Magnesite can be distinguished from these minerals by its higher specific gravity and its behavior towards acids, being more difficultly soluble; it is almost insoluble in cold acids, but when powdered dissolves readily in warm HCl.

The most noteworthy deposits of crystalline magnesia are in Austria-Hungary, Quebec and Washington. It almost invariably occurs in association with dolomite, with which its origin is closely connected. It is generally held that the Austro-Hungarian deposits are limestone replacements, formed by the action of ascending aqueous solutions carrying magnesium carbonate and high in iron compounds. These solutions penetrated the limestone beds, forming dolomite and magnesite through replacement of lime by magnesia.[1] A somewhat similar origin is attributed to the crystalline magnesite of Quebec,[2] although in this case the circulating waters were not high in iron. The Washington deposits occur in sedimentary rocks, probably of Paleozoic age, not far distant from igneous intrusives. It is believed that these magnesite deposits represent replacements of dolomite bodies, and that the intrusives were the source from which replacement was effected through the agency of circulating waters.[3]

There are many deposits of crystalline magnesite of the breunnerite type in Styria, Lower Austria, and Northern Hungary, of which about a dozen are large enough to be commercially workable. The Styrian and Lower Austrian deposits occur in a belt

[1] K. Redlich, "Genesis of the Pinolite Magnesite, Siderite and Ankerite of the Eastern Alps," *Mineralog. petro. Mitt.*, **26,** 499 (1912); J. Hörhager, "The Formation of Magnesite Deposits and their Association with Iron Ore Beds," *Oester. Z. Berg.-Hüttenw.*, **59,** 222 (1910).

[2] M. E. Wilson, "The Magnesite Deposits of the Grenville District, Quebec," *Memoir 98 of Canadian Geol. Survey*, **34** (1917).

[3] Olaf P. Jenkins, "Notes on the Possible Origin of the Magnesite Near Valley, Washington," *Econ. Geol.*, **13,** 381 (1918).

southwest of Vienna, extending from the Semmering to the Tyrol; some of them are less than 100 miles from the Adriatic Sea. The most important occurrences, taken in order from east to west, are those at Semmering, (Eichberg) Veitsch, Brietenau, Trieben, Redenthein (Minstatt) and Dientin (Salzburg). The formation extends eastward beyond Vienna into Northern Hungary, where magnesite is quarried between Jolsva and Nyustya, at a distance of 360 miles from Fiume, the nearest port on the Adriatic.[1] Most of the material exported has come from Styria and Lower Austria on account of the much shorter distance to the shipping point on the coast.

The Austrian magnesite occurs in the form of huge lenticular masses in a belt of carboniferous rocks consisting mainly of metamorphosed shales, sandstones, and conglomerates. The largest and most celebrated deposit is the one at Veitsch near Mittendorf station in Styria. It was acquired by Carl Spaeter in 1880, and mining began in 1881 with small output. The lens is nearly three-quarters of a mile long and over 1000 feet in width and probably continues to a considerable depth. The magnesite is mottled, of various shades of grays and drabs, but turns brown on exposure to the air on account of oxidation of the ferrous carbonate. It is quarried in a series of terraces, 50 feet apart vertically, extending from the summit of the hill to the base of the deposit 700 to 800 feet lower.[2] The large blocks of stone blasted from the quarry face are broken to pieces of head size and cobbed to remove impurities such as schist, dolomite and quartz; and lumps high in impurities are reduced to fist-sized pieces for further dressing. The loss in sorting is said to amount to one-half to two-thirds of the material quarried. After separation from the waste rock, the magnesite is transported by gravity planes to the calcining plant at the foot of the hill. It is said to show the following range of composition:

$MgCO_3$	83 to 94.0%
$CaCO_3$	0.5 to 4.5
$FeCO_3$	4 to 12
SiO_2	up to 3
Al_2O_3	up to 1
Mn_2O_3	up to 0.5

[1] Thomas Crook, *op. cit.*, p. 79; Anonymous, "An Austrian Magnesite Property Developed by American Capital," *Iron Trade Rev.*, **55**, 772 (1914).

[2] L. C. Morganroth, "The Occurrence, Preparation and Use of Magnesite," *Trans. Am. Inst. Mining Eng.*, **50**, 890 (1914).

Although the crude magnesite shows considerable variation in the content of ferrous carbonate, the dead-burned product as marketed is very uniform in composition, on account of the care in treatment and the thoroughness of mixing.

Quebec.—In the Grenville district, Quebec, crystalline magnesite occurs in large lenticular masses in the Grenville series of metamorphic sedimentary rocks, intimately associated with serpentine and dolomite. Masses of the latter, of irregular size and shape, are scattered throughout the deposits. The magnesite is snow-white to grayish, finely crystalline, and high in lime due to dolomite inclusions. Wilson in 1917 estimated that there were in sight a little less than 700,000 tons containing under 12 per cent CaO, much of which contained no more than 7 per cent to 10 per cent CaO (equivalent to 12.5 to 18 per cent $CaCO_3$). The deposits were opened in a small way in 1907, but no shipments of consequence were made prior to the war. During the war magnesite was quarried by two companies, and is still being produced, though in diminished quantity. The output has been used almost wholly for the production of dead-burned grains for furnace bottoms as a substitute for Austrian magnesite; on account of the high lime content, the product is not considered very desirable for this purpose and has been largely supplanted by the purer material from Washington.

Washington.[1]—The Washington magnesite deposits occur near Valley and Chewelah, on the Great Northern Railroad, about sixty miles north of Spokane. Shipments began in 1916 with an output of 715 tons of crude magnesite; in 1917, 105,175 tons were produced, and in 1918, 147,528 tons.

The mineral varies from 93 to 97.5 per cent $MgCO_3$; it is finely to coarsely crystalline and shows many variations in color from white to gray, pink, red and black, although pink and light gray are the predominant colors. It occurs as huge steeply pitching

[1] R. W. Stone, "Magnesite Deposits of Washington," *Eng. Mining J.*, **105,** 665 (1918); C. D. Dolman, "Magnesite: Its Geology, Products and their Uses," *Bull.* **152**; *Am. Inst. Mining Met. Eng.*, 1193 (1919); C. G. Yale and R. W. Stone, "Magnesite in 1917," Mineral Resources of the United States, 1917 (1918), Pt. II, p. 65.

lenses in thick dolomite beds which are overlain by quartzite, underlain by shale and slate and associated with igneous greenstone. There are six or seven known deposits in the district, and

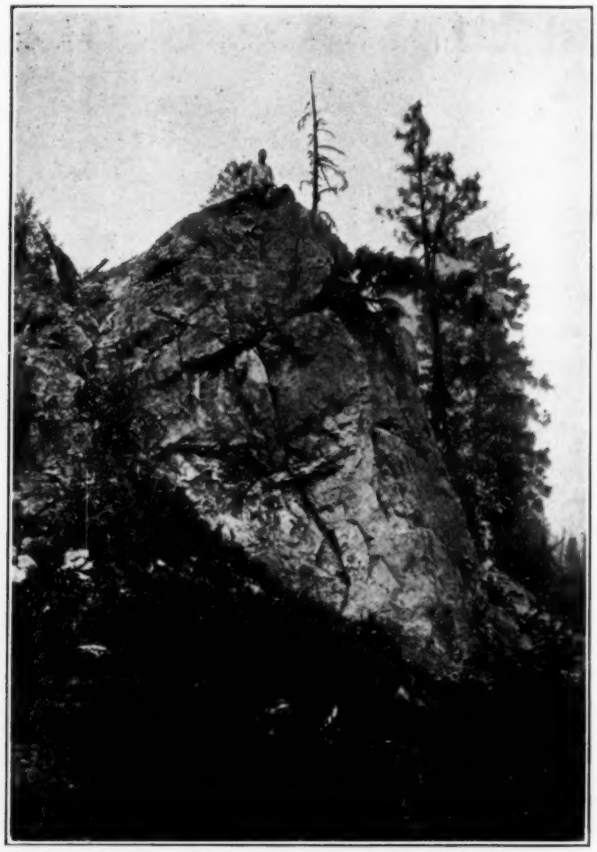


FIG. 1.—A magnesite outcrop near Chewelah, Washington

the amount available from them all has been estimated at not less than seven million tons, with a probability that more will be developed by future exploratory work. The Finch deposit of the Northwest Magnesite Company has a length of 1500 feet and a thickness of 200 feet, and it is reported that diamond drilling

has proven the existence of more than 1,000,000 tons of high-grade magnesite. The Red Marble deposit is about a quarter of a mile long and 200 to 300 feet thick. Other important deposits are the Allen, Double Eagle and Keystone.

The material shipped by the Northwest Magnesite Company, which is secured from the Finch quarry, is mined from a deep open-air pit sunk on the mountain side, such as is commonly known as a "glory-hole." The glory-hole has a horizontal floor with two chutes which connect with a level at a lower elevation; one chute is used for good magnesite, the other for waste. The magnesite, after being blasted down from the sides of the hole, is broken with sledges to pieces of one-man size. Fine material, which is high in silica, is screened out with pitchforks. The waste amounts to about 20 per cent of the total. Good rock and waste are drawn from the chutes into cars on the lower level, and the good magnesite is given a preliminary crushing before transportation to the calcining plant. This is five miles distant on the Great Northern Railroad near Chewelah.

TYPICAL ANALYSES OF WASHINGTON MAGNESITE

SiO_2	1.9	3.3	4.3	0.6
Fe_2O_3 and Al_2O_3	1.0	1.0	0.8	1.2
CaO	1.7	1.4	1.1	0.5
MgO	45.2	44.8	45.0	46.4
CO_2	49.7	49.3	49.5	51.0
	99.5	99.8	100.7	99.7

Cryptocrystalline Magnesite

Cryptocrystalline, or amorphous magnesite occurs in serpentine in the form of irregular veins, lenses, reniform masses and stockwork. It is believed to be one of the decomposition products formed during the serpentinization of magnesian-silicate rocks, such as olivine and enstatite, and during the subsequent decomposition of the serpentine through the action of waters bearing CO_2.[1] The most important deposits are those of Greece and California; it is found also in India, near the town of Salem; in

[1] S. H. Dolbear, "The Origin and Geo-Chemistry of Magnesite," *Mining Sci. Press*, **114**, 237 (1917).

the Transvaal; in Venezuela; on Santa Margarita and Cedros Islands, off the west coast of Mexico; and in many other places.

Greece.[1]—The most widely known deposits of amorphous magnesite are those on the Island of Euboea, Greece. They vary considerably in size, but are larger than most deposits of this type. The bodies range from $6^1/_2$ to 130 feet in thickness and up to 500 feet in length; the depth to which mining operations can be carried rarely exceeds 200 feet. The magnesium carbonate content varies from 94 per cent to 98 per cent, and the impurities are correspondingly low, although careful sorting at the mines is necessary in order to remove serpentine and other waste material. When this is not done, the silica and lime content is likely to be high.

These deposits have been worked for many years. Export began in 1870; by 1899 the annual output had risen to 35,000 tons. The amount produced in recent years, expressed in metric tons,[2] is as follows:

1911.....	86,956	1914.....	136,701
1912.....	106,338	1915.....	159,981
1913.....	118,054	1916.....	199,484

Considerable Grecian magnesite was shipped to the United States during 1915 and 1916, but shipments were suspended late in 1916, and no more was imported while the war lasted.

California.[3]—Amorphous magnesite occurs at many places in California, in veins and lenses which are usually small, and which show considerable variation in length and thickness. Although it has been mined in ten or twelve counties, the largest and most important deposits are those at Porterville, Tulare County, and St. Helena, Napa County. At Porterville there are many veins, averaging four to five feet in thickness; the main body at the

[1] W. Donald, *op. cit.*, p. 96; J. Hogg, "Magnesite Deposits in Euboea, Greece," *Trans. Inst. Mining Eng.*, **46,** 128 (1914).

[2] Metric ton = 1.1023 net tons.

[3] Frank L. Hess, "The Magnesite Deposits of California," *Bull.* **355,** U. S. Geol. Survey (1908); Anonymous, "California Magnesite," *Iron Age,* **99,** 845 (1917); W. C. Phalen, "Magnesite Industry in the United States," *Mining Sci. Press,* **119,** 295 (1919); S. H. Dolbear, "Magnesite Deposits and Possibilities in California," *Mining Press,* **110,** 105 (1915).

White Rock deposit, near St. Helena, is over 20 feet thick. Mining is usually done by running levels, stoping out the magnesite, and back-filling. Prior to 1914 about 10,000 tons were being produced annually; in 1917 this had grown to 211,773 net tons. In the following year the production dropped to 84,077 tons and in 1919 to about 60,000 tons.

TYPICAL ANALYSES OF CALIFORNIA CRUDE MAGNESITE

SiO_2	3.25	5.18	1.10	3.86	1.55
Fe_2O_3 and Al_2O_3	2.20	1.10	0.40	0.80	0.45
CaO	1.25	3.34	Trace	2.04	1.38
MgO	43.87	41.92	46.47	43.47	45.68
CO_2	49.53	48.78	51.20	49.48	50.97
	100.10	100.32	99.24	99.65	100.03

PART III. MANUFACTURE OF MAGNESITE PRODUCTS

Nomenclature

The names applied to the different magnesite products are somewhat confusing, as they are not infrequently used interchangeably to designate products dissimilar in character. The definitions given below are believed to represent common usage.

MAGNESITE: (1) The mineral $MgCO_3$, the crude material of the magnesite industry; (2) a term applied to various products manufactured from the mineral $MgCO_3$, such as "dead-burned" and "plastic" magnesite, magnesite brick and so forth.

PLASTIC MAGNESITE OR CAUSTIC BURNED MAGNESIA: The product which results from calcining crude magnesite at a comparatively low temperature, and which contains about 2 per cent to 5 per cent CO_2; called also calcined magnesite.

CALCINED MAGNESITE: (1) Magnesite which has been calcined at any temperature, including both caustic and dead-burned; (2) an intermediate product between caustic and dead-burned magnesite, *i. e.*, magnesite which has been calcined but not sintered, and in which the CO_2 content is below 2 per cent, usually about 1 per cent.

DEAD BURNED MAGNESITE OR DEAD BURNED MAGNESIA: A sintered product obtained by calcining magnesite at a high temperature; it usually contains less than 0.5 per cent CO_2 and almost invariably contains 4.5 to 8 per cent Fe_2O_3, either naturally or by additions of iron ore during the treatment.

ELECTRICALLY SHRUNK MAGNESIA: Magnesite calcined in the electric furnace to effect complete shrinkage; usually of a high degree of purity.

MAGNESIA OR MAGNESITE BRICK: Brick consisting essentially of MgO, generally containing 4.5 to 8 per cent Fe_2O_3. It has been suggested that brick with this amount of iron be called "magnesite brick," and those nearly free from iron "magnesia brick," but the latter term is more frequently applied to both.

MAGNESIA: (1) The pure oxide of magnesium; (2) a term applied synonymously with "magnesite" to brick, dead-burned material, and so forth; (3) to certain magnesite products low in impurities and high in MgO, as magnesia crucibles, electrically shrunk or fused magnesia, and so forth, and (4) also applied to precipitated or basic carbonate of magnesia.

BASIC CARBONATE OF MAGNESIA: A light powdery material prepared either by boiling a solution of acid magnesium carbonate, or by double decomposition of a soluble magnesium salt and a soluble carbonate. The composition of the commercial product varies somewhat, but is generally given as $3MgCO_3 \cdot Mg(OH)_2 + 3H_2O$, the same as that of hydromagnesite.

Calcination of Magnesite

The first step in the preparation of magnesite products is calcination of the crude mineral, in order to drive off more or less completely the carbon dioxide with which the magnesia is chemically combined. This treatment causes a loss of about 50 per cent in weight, a considerable decrease in volume, and marked changes in physical properties. The character of the resultant product is dependent upon the time and temperature of calcination, and the amount and composition of impurities present. Caustic burned magnesia is produced by calcining the crude material at a temperature of 700° to 1000° C. It contains from about 2 to 5 per cent CO_2, and on account of its setting properties when mixed with a solution of magnesium chloride, is used as a flooring material and for the production of artificial stone and so forth. For this purpose the amorphous type of magnesite is preferred to the crystalline, because of its white color and lower content of impurities.

Dead-burned magnesite[1] results from calcining either the crude or the lightly calcined material at a temperature that will not merely drive off nearly all the CO_2, but will also cause sintering of the particles. During this process the pieces shrink consid-

[1] J. Hörhager, "On Magnesite," *Stahl u. Eisen*, **31**, 958 (1911); H. O. Hoffman, "General Metallurgy," published by McGraw-Hill Book Co., 1913, p. 370.

erably and become hard, dense, and inert to atmospheric moisture and CO_2. The temperature at which this occurs depends on the texture and composition of the crude magnesite. One high in iron oxide, such as the Styrian, will shrink and frit together at 1450° to 1500° C; while a temperature of 1600° to 1700° C or higher is required for one low in iron oxide and other impurities. For this reason a small percentage of iron oxide is considered necessary for the production of dead-burned magnesite satisfactory for most refractory purposes, which will not be subject to further shrinkage at furnace temperatures and which will sinter together to form a well-bonded furnace hearth at working temperatures. From 4.5 per cent to 8 per cent Fe_2O_3 in the dead-burned grains is regarded as the most desirable amount. If the crude material used is too low in iron, the oxide may be added in the form of iron ore; the ore and the magnesite should be finely ground and intimately mixed before calcination. Prior to the war the Austrian crystalline magnesite was used exclusively for the production of dead-burned magnesite, since it naturally contains the amount of iron oxide considered to be most satisfactory.

The fact that amorphous magnesite is preferred for the production of caustic magnesia, and the crystalline variety for that of dead-burned magnesite, has often led to the conclusion that amorphous magnesite only can be used in the manufacture of caustic burned magnesia, and the crystalline magnesite only in the preparation of dead-burned magnesite. As a matter of fact, caustic burned magnesia of excellent grade (color excepted) has been produced from crystalline magnesite;[1] and dead-burned magnesite of high quality has been produced in this country since 1914 from magnesite of the amorphous type.

When calcined in the lump form, amorphous magnesite develops a columnar structure; the Austrian crystalline magnesite retains its cleavage form and shows rhombohedral fragments even when calcined. The coarseness of texture of many crystalline magnesites is an advantage, as dolomitic impurities are likely to be less intimately admixed when the texture is coarse than when it is

[1] R. D. Pike, Northwest Magnesite Company, private communication.

fine, and their removal is, therefore, easier. The effect of the crystal cleavages in giving the kiln gases access to the interior of all lumps is to decrease fuel consumption, and may be partly responsible for the fact that crystalline magnesite is more easily calcined than is the amorphous variety.

By calcination in the electric furnace above 1700° C, pure magnesite may be shrunk to a hard, flinty mass, with a specific gravity of about 3.65, which shows no additional shrinkage on further heating.[1]

Austria.[2]—In Austria magnesite is dead-burned in shaft kilns of the bottle type and in rotary kilns. The former are fired with producer gas and produce 15 to 24 tons of sintered product in 24 hours; the rotary kilns, fired with powdered coal, produce 50 to 60 tons per day. Less fuel is required when the ferrous carbonate content of the magnesite is fairly high than when it is low. Good flaming brown coal with a calorific value of 6000 calories is used, and the consumption is said to vary from 600 to 800 pounds per ton of dead-burned material. The abundance and accessibility of the brown coal have been important factors in the development of the Austrian magnesite industry.

After calcination, the magnesite must again be sorted to remove impurities not discarded at the quarries. Separation from impurities is facilitated by the dark color and magnetic properties acquired in burning, both of which are imparted by the iron present. The sintered material is crushed and sized mechanically, and the coarser particles are usually hand picked to sort out under-burned grains, as well as talc, dolomite and quartz. Much of the lime present falls readily to dust, and is removed by the first screening. Magnetic separation is practiced at some plants.

The Austrian magnesite formerly imported into the United States had approximately the following analysis:

[1] R. C. Gosrow, "Refractory Magnesia," *Met. Chem. Eng.*, **17**, 415 (1917).

[2] L. C. Morganroth, "Occurrence, Preparation and Use of Magnesite," *Trans. Am. Inst. Mining Eng.*, **50**, 890 (1914); Anonymous, "Works of the Austro-American Magnesite Co.," *Iron Trade Rev.*, **48**, 111 (1911); Anonymous, "An Austrian Magnesite Property Developed by American Capital," *Ibid.*, **55**, 772 (1914).

	Range	Average
MgO	83.0–89.0	85.6
CaO	1.5– 4.0	2.9
SiO_2	1.0– 4.0	2.8
Al_2O_3	0.2– 1.5	0.6
Fe_2O_3	4.0– 8.5	7.1
Mn_3O_4	0.5– 0.8	0.6

Greece.—Large bottle-shaped kilns, fired with producer gas, are used on the Island of Euboea in calcining magnesite for export. Prior to the war over half the magnesite produced was calcined to the caustic condition and shipped to Germany, where it found application principally as a building material.

Canada.—At Hull, Quebec, 60-foot rotary kilns, with powdered coal as fuel, were used during the war for calcining magnesite from the Grenville district. It is said that after crushing, the crude mineral was mixed with several per cent of magnetic iron ore, ground in a ball mill, and burned in the rotary kilns, forming sintered nodules of a dark brown color. The analysis of the grains produced is approximately as follows:

MgO	67.5
CaO	17.7
SiO_2	5.5
Al_2O_3	2.0
Fe_2O_3	7.1

California.[1]—In California magnesite is calcined in bottle-shaped and vertical shaft kilns and in rotary kilns. The material charged into shaft kilns must be in the lump form as the draft would be choked by fines. For feeding into rotary kilns the lumps are first crushed, in some plants to $1\frac{1}{2}$ inch diameter, and in others to $\frac{1}{2}$ inch diameter or smaller. The latter practice is the more recent, and is considered the more satisfactory.

A vertical shaft kiln of the customary size produces about 7 to 10 tons of calcined magnesite in 24 hours, a bottle-shaped kiln 15 to 20 tons, and a 125-foot rotary, $7\frac{1}{2} \times 7$ feet in diameter 60 to 75 tons. The total calcining capacity of all the plants in California is estimated at 10,000 to 12,000 tons per month. The greater portion of their output is not dead-burned and is, there-

[1] W. C. Phalen, "The Magnesite Industry in the United States," *Mining Sci. Press*, **119**, 295 (1919).

fore used otherwise than as a refractory material. Distillate and crude oil are the usual fuels, but coke is used in some plants. It is generally estimated that in the rotary kilns 1 to $1^1/_3$ barrels of crude oil are consumed per ton of magnesite when the latter is burned to 0.5 per cent ignition loss, but not sintered with iron. At the White Rock Mine in Napa County, Alabama coke is charged in layers with the magnesite in vertical kilns, and it is stated that 320 pounds of coke are required per ton of dead-burned magnesite produced.

On account of the low content of iron of nearly all Californian magnesite, very little can be used for the manufacture of refractory magnesite without the addition of iron. In two producing mines of the state, however, the calcined product naturally contains an average of 4.5 per cent iron oxide and alumina. Such material turns reddish brown in burning; magnesite free from iron remains perfectly white, and for that reason is preferred as a plastic flooring material.

Washington.—The largest producer in the Washington field is the Northwest Magnesite Company, which has five $7^1/_2 \times 125$-foot rotary kilns at Chewelah, with a total rated capacity of 9,000 tons of dead-burned magnesite per month. The lumps of magnesite coming from the mine are finely ground and mixed with $2^1/_4$ per cent of iron ore before feeding into the kilns. Pulverized coal with about 13,000 B.T.U.'s per pound is used as fuel, and the consumption is about 800 lbs. of coal per ton of dead-burned magnesite produced.[1] The heat of the kilns causes the finely pulverized material to sinter together, forming dense, hard nodules. The dead-burned product on coming from the kilns is passed through a rotary cooler, then crushed by rolls to the proper size. The average analysis of the dead-burned magnesite produced by the Northwest Magnesite Company is given below:

AVERAGE ANALYSIS OF NORTHWEST MAGNESITE COMPANY PRODUCT, JULY 1918 TO NOVEMBER 1919[2]

MgO	83.04
CaO	3.11
Mn_2O_3	Trace
Fe_2O_3 and Al_2O_3	7.02
SiO_2	6.78

[1] R. D. Pike, Northwest Magnesite Co., private communication.

[2] Advertising booklet of Northwest Magnesite Co. (1919).

Magnesia Crucibles

Small magnesia crucibles are made for various purposes; for muffle use they have been prepared by machining magnesite brick.[1] For preparing ferro-alloys, O. P. Watts[2] has made magnesia linings for graphite laboratory crucibles, to prevent contamination of the charge by carbon from the graphite. Calcined magnesia, moistened with water, was tamped around a wooden core in a graphite crucible. After removal of the core, the lining was dried in an oven and burned in a carbon resistance furnace, at a temperature above that to be used in forming the alloys. Iron oxide, when present in the magnesia, was harmful, for it distilled out in the burning, and corroded both the crucible and the magnesia lining. Average linings 6 inches high and $3^1/_8$ inches in diameter shrunk 17 per cent in length and 12 per cent in diameter during the burning. After burning they could be readily removed, were hard and stone-like, and showed a crystalline fracture. However, they could not be handled at a white heat, and it was found necessary to replace them in the graphite crucible for use at high temperatures. Attempts to increase the strength at high temperatures by the addition of other refractory materials to the magnesia were not successful. The maximum temperature to which the crucibles could be used was fixed by the reduction of the magnesia by the graphite.

Yensen[3] has made magnesia crucibles for laboratory purposes from calcined magnesia fused in an electric arc furnace. The fused magnesia was crushed to pass a 40-mesh screen, mixed with 5 per cent hydrated magnesia, molded into crucibles under heavy pressure in a steel mold, dried and heated to 1800° C in an electric furnace. The crucibles were said to be uniform and strong, with little shrinkage, and to show no sign of softening at 1800° C. The magnesia used contained 5 per cent impurities. Fitzgerald[4] had previously found that a crucible made from Grecian

[1] Donald M. Liddell, "Magnesite Crucibles," *Eng. Mining J.*, **96**, 503 (1913).

[2] O. P. Watts, "Making of Magnesia Crucibles," *Mining Sci.*, **66**, 413 (1912).

[3] T. D. Yensen, "Magnesia Ware," *J. Am. Ceram. Soc.*, **1**, 730 (1918).

[4] F. A. J. Fitzgerald, "Refractories," *Met. Chem. Eng.*, **10**, 129 (1912).

magnesite of a high degree of purity and said to be "highly calcined" cracked so badly as to be useless when heated gradually to 1500° C and cooled slowly; while one of material which had been electrically calcined developed only a few small cracks and was otherwise in good condition after fairly rapid heating to above cone 35 (*i. e.*, above 1755° C), followed by slow cooling.

Manufacture of Magnesia Brick[1]

Magnesia brick is commonly made from dead-burned magnesite containing 4.5 to 8 per cent Fe_2O_3, although for special purposes a few are manufactured from magnesite low in iron such as the Grecian. It is essential, in order to minimize burning shrinkage, that the material used be thoroughly dead-burned to a high specific gravity.

The use of bonding material is not customary in American practice. Caustic magnesite was at one time generally employed for this purpose, but it is not now favored for, while it is an advantage in molding, it has the disadvantage of high burning shrinkage. In Europe serpentine has been used to bond the amorphous magnesite of Greece; clay up to 15 per cent has likewise been tried, but it decreased the refractoriness to an excessive degree. Brick made with a binder of silicate of soda proved mechanically weak at high temperatures and readily cracked. Temporary bonds, such as tar, molasses, and dextrine are more or less employed in Europe to hold the particles together before burning.

In the early nineties bricks were being made at Brieg in Silesia from dead-burned amorphous magnesite bonded with caustic magnesite to which magnesium chloride had been added. They were molded in a hydraulic press at about 1500 pounds pressure per square inch.[2] In Europe, up to a few years before the war,[3]

[1] E. T. Montgomery, "Refractory Brick," *Brick and Clay Record*, **44**, 1144 (1914); A. B. Searles, "Refractory Materials," Chas. Griffin & Co., 242 (1917).

[2] Thomas Crook, *op. cit.*, p. 70.

[3] C. Schimm, "Burning of Magnesite and Magnesite Brick," *Stahl u. Eisen*, **26**, 303 (1906); J. Hörhager, "On Magnesite," *Stahl u. Eisen*, **31**, 955 (1911); Dr. Kern, "Magnesite and Its Technical Utilization," *Glückauf*, **48**, 271 (1912).

the dead-burned magnesite, after crushing and sorting, was ground in edge-runner or ball mills to $1\frac{1}{2}$ millimeters (about $\frac{1}{16}$ inch). The specific gravity was often obtained to give an indication of the amount of shrinkage likely to occur, and to permit of definite volume weight to be made from material of different batches. Ten per cent of caustic magnesite at times was added as a bond, but was more frequently omitted. The ground mass was moistened with 4 to 5 per cent of water, sometimes though not usually, with the addition of dextrine or similar binder, and mixed in a trough mixer or pan mill. After mixing, it was in some cases allowed to stand from 2 days to 3 weeks before pressing. It was molded in a hydraulic press at 3500 to 7000 pounds per square inch, depending upon the character of the magnesite used, and its difficultly of sintering. Material which could be easily sintered was given the lower pressure. The green bricks were dried slowly, sometimes in dryers heated by waste steam, at others in well-ventilated sheds heated only in the winter months. They were commonly, but not always, burned in the same kiln with silica brick, being set in the upper part of the kiln on top of the latter, and surrounded by silica brick for protection from the flames. The maximum burning temperature was maintained 24 hours; it was usually about cone 18, although some German manufacturers heated to cone 26. It has been stated that brick burned to cone 30 to 34 shrink to such an extent that they can be used in furnace arches.

In the United States, the dead-burned magnesite, after having been finely ground, is thoroughly mixed in a wet pan with a small amount of water. The bricks are molded, as a rule, in a power press. The green brick, placed on rack cars, are dried in tunnel driers; they are extremely fragile before drying, but are usually hard and tough when dry. They must be set in the kilns with care, as they are easily deformed during burning by a slight load. For this reason they are boxed in with silica brick in such a way that there is practically no load upon them. Burning takes place in rectangular down-draft kilns; cooling is done slowly in order to avoid cracking of the brick. The burning shrinkage amounts to about $\frac{3}{32}$ to $\frac{1}{8}$ inch per foot.

An ingenious form of magnesite brick, said to be especially

adapted for service in open-hearth and electric furnaces, has been put on the market within the last few years under the trade name of "metalkase brick."[1] These bricks consist of round or square soft steel containers, open at the ends and of a convenient size for handling and laying, packed with dead-burned magnesite.

PART IV. PROPERTIES OF CAUSTIC, DEAD-BURNED, AND FUSED MAGNESIA

Color, Texture, etc.—The caustic burned magnesia sold for various purposes is usually white, the color preferred by most users; it is sometimes buff or reddish brown, depending upon the amount and character of the impurities present. It is easily pulverized, and lumps fall readily to powder upon exposure to the air.

Dead-burned magnesite is red, reddish brown, chocolate brown, black, or of intermediate color. Iron oxide in the absence of manganese imparts a reddish color, while the combined coloring effect of iron oxide and small quantities of manganese produces rich chocolate brown to black. Dead-burned magnesite is hard and dense; it is marketed in the form of nodules or grains varying from $^5/_8$ inch diameter to extremely fine particles.

Fused magnesia prepared in the electric furnace is generally low in impurities and white in color. It is very hard (hardness 5 to 6) and resembles glazed porcelain. When cooled rapidly the crystals are minute and compact; if cooled slowly they are fairly large and in well-defined layers.[2]

The latent heat of fusion of MgO is 700 (±15 per cent) calories per gram.[3] Its fusion point is 2800° C,[4] although it becomes somewhat plastic and mechanically weak at temperatures far below this. At 1000° C below its melting point it will bond together to a dense mass which is hard and strong when cold.

[1] W. F. Rochow, "The Selection of Refractories for Industrial Furnaces," *J. Ind. Eng. Chem.*, **11**, 1146 (1919).

[2] Goodwin and Mailey, "Properties of Fused Magnesium Oxide," *Trans. Am. Electrochem. Soc.*, **9**, 89 (1906).

[3] E. W. Washburn, "Latent Heats of Fusion of Lime and Magnesia," *Trans. Am. Ceram. Soc.*, **19**, 195 (1917).

[4] C. W. Kanolt, "The Melting Points of Some Refractory Oxides," *J. Wash. Acad. Sci.*, **3**, 315 (1913).

This fact suggests that MgO has an appreciable vapor pressure at temperatures much lower than the melting point. Commercial dead-burned magnesite, containing 12 per cent impurities, does not melt at 2000° C.[1] W. R. Mott[2] has given the boiling point of magnesia as 3600° C, lime 3400° C, and alumina 3800° C.

Specific Heat.—The mean specific heat of pure magnesia at various temperatures is as follows:

Degrees centigrade			Mean specific heat between	
t_1	t_2	Mean t	t_1 and t_2	Observer
−191	−80	−135	0.1006	Russell[3]
− 79	0	− 39	0.1933	Russell
22	99	61	0.2340	Magnus[4]
15	268	142	0.2520	Magnus
15	559	287	0.2670	Magnus
16	765	390	0.2762	Magnus

Microscopic Structure, Specific Gravity and Shrinkage.—In the calcination of magnesite, either of the crystalline or the dense variety, the product first resulting from the dissociation of $MgCO_3$ consists of very fine grained amorphous magnesia,[5] with a specific gravity of about 3.2,[6] called α-magnesia by Mellor. This, if heated at a sufficiently high temperature, is gradually transformed into the mineral periclase, Mellor's β-magnesia, the specific gravity of which is 3.674. Caustic burned magnesia is composed essentially of amorphous magnesia, while the dead-burned material is largely periclase. The theoretical volume shrinkage accompanying the transformation is 13 per cent; the total shrinkage is actually greater than this, on account of crystal-growth and change in porosity.

[1] Raymond M. Howe, private notes.

[2] Meeting of Am. Electrochem. Soc., Oct. 2, 1918.

[3] A. S. Russell, "Measurements of Specific Heats at Low Temperatures," *Phys. Ztg.*, **13**, 59 (1912).

[4] A. Magnus, "Measurements of the Specific Heats of Solids at High Temperatures," *Ibid.*, **14**, 5 (1913).

[5] J. W. Mellor, "Spalling of Magnesite Bricks," *Trans. Ceram. Soc. (Eng.)*, **16**, 85 (1916–17).

[6] J. W. Mellor (*op. cit.*) gives this figure; W. Donald gives 3.01. (W. Donald, "Magnesite and Magnesite Brick," *Trans. Ceram. Soc. (Eng.)*, **17**, Pt. II, 504, (1917–18).

Not only because of the chemical activity of amorphous magnesia, but also on account of the shrinkage, material to be used for refractory purposes should show a high degree of conversion to periclase. The completeness to which the transformation has taken place may be estimated from specific gravity determinations. The higher the specific gravity, the less will be any additional shrinkage on reheating to high temperatures.

Commercial caustic magnesite has a specific gravity from 3.20 to 3.30; higher values indicate overburning. The density of dead-burned magnesite is slightly less or greater than 3.50.

Moissan[1] found fused magnesia to have a specific gravity of 3.577 to 3.654. The latter figure was obtained on a 50 gram specimen which had fused into a single piece in the electric furnace. Fitzgerald and Bennie[2] report a specific gravity of 3.572 for fused magnesia containing about 6 per cent impurities.

Chemical Composition.—The chemical analyses of caustic and electrically fused magnesite will not be given here; they are usually low in impurities. The effect of the fluxing impurities contained in dead-burned magnesite will be discussed from a theoretical standpoint in the notes on microscopic examination, and the comments here made will, therefore, pertain merely to industrial practice.

Commercial dead-burned magnesite and brick made therefrom have the following average analyses:

Oxide	Austrian	Washington
MgO	85.6	83.1
CaO	2.9	3.1
SiO_2	2.8	6.8
Al_2O_3	.6	2.0
Fe_2O_3	7.1	5.0
Mn_3O_4	.6	Trace

With the proportion of Fe_2O_3 shown in the above analyses, dead-burned magnesite has a long range of vitrification and develops good bonding properties at 1500°–1600° C, so that objects made from it and burned at that temperature are mechanically

[1] H. Moissan, "Determinations of the Density of MgO," *Compt. rend.*, **118**, 506 (1894).

[2] Fitzgerald and Bennie, *Trans. Am. Electrochem. Soc.*, **9**, 101 (1906).

strong. The proper proportion of iron is somewhat dependent upon the silica content as less is required when the silica content is high than when it is low. Since silica exerts considerable fluxing action when present in excessive amounts, particularly when the lime content is high, its percentage should preferably be less than 8 per cent of the total. It is generally held that CaO in excess of 5 per cent is objectionable, on account of its tendency to slake at ordinary temperatures, and to combine with other elements at high temperatures. CO_2 should be low, preferably under 0.5 per cent.

Crushing Strength of Magnesia-Silica Mixtures at High Temperatures.[1]—The effect of varying the proportion of silica, upon the hot crushing strength of cylinders made of MgO-SiO_2 mixtures has been studied by Kowalke and Hougen. Pure magnesia was calcined at about 1500° C., ground to 40 mesh, mixed with varying amounts of 40-mesh quartz, moistened with 10 per cent water, molded into cylinders at 1500 pounds per square inch, dried and baked in a carbon resistance furnace to about 2100° C. These cylinders were subjected to a constant load of 66.5 pounds per square inch and heated at a uniform rate until failure had occurred. The pure magnesia cylinders failed slowly and gradually; the MgO-SiO_2 mixtures always failed abruptly. A maximum hot crushing strength was developed in mixtures containing $7\frac{1}{2}$ per cent SiO_2, which failed at a temperature 190° C higher than pure magnesia. The results were as follows:

Silica content, per cent	Average temperature of failure
0	1680° C
3	1800° C
6	1850° C
7	1860° C
$7\frac{1}{2}$	1870° C
8	1852° C
12	1838° C

Electrical Resistivity.—Northrup[2] gives the following figures for the electrical resistivity of electrically shrunk magnesia, to which 10 per cent pure $MgCO_3$ had been added for bonding:

[1] Kowalke and Hougen, "Crushing Strength of Magnesia-Silica Mixtures at High Temperatures," *Trans. Am. Electrochem. Soc.*, **33**, 215 (1918).

[2] E. F. Northrup, *Ibid.*, **27**, 233 (1913).

Temperature	Resistivity in ohms per cm. cube
1060° C	420,000
1100°	320,000
1170°	62,000
1230°	24,000
1352°	510
1386°	415

According to Goodwin and Mailey[1] fused magnesia has a higher electrical resistivity than porcelain below 1100° C, but lower above that temperature. Brace[2] found that, as compared with electrical porcelain, calcined magnesite has a higher electrical resistivity at all temperatures from 439° to 990° C; its ratio of initial to final resistivity is higher, and its resistivity comes to a steady value more quickly.

Thermal Expansion.—The coefficient of expansion of fused magnesia[3] is not greatly different from that of platinum, being 1.14×10^{-5} at 120° C and 1.278×10^{-5} at 270° C, compared with 0.904×10^{-5} and 0.923×10^{-5} for platinum at the same temperatures. On account of the low expansion, objects made of fused magnesia will not crack with fairly rapid changes of temperature.

Hydration and Slaking.—At ordinary temperatures caustic burned magnesia forms a hydrate which is slightly plastic and can be molded, and rapidly takes up H_2O and CO_2 from the air. Since the commercial value is largely dependent upon its property of combining with water, carbon dioxide, magnesium chloride and certain other compounds, its degree of chemical activity is of considerable importance.

Gosrow[4] has studied the rate of hydration of caustic calcined amorphous magnesite, by exposing one-quarter inch lumps to the action of moist air, and determining the increase in weight at definite intervals. The following results were obtained:

[1] Goodwin and Mailey, "Properties of Fused Magnesium Oxide," *Trans. Am. Electrochem. Soc.*, **9**, 89 (1906).

[2] P. H. Brace, "Electrical Resistivity of Porcelain and Magnesia at High Temperatures," *Ibid.*, **33**, 205 (1912).

[3] Goodwin and Mailey, *op. cit.*

[4] R. C. Gosrow, "Refractory Magnesia," *Met. Chem. Eng.*, **17**, 415 (1917).

Analysis of material used		Time of exposure to moist air, hrs.	Increase in weight, per cent
MgO	94.70	30	2.50
CaO	0.10	44	3.25
R_2O_3	1.90	76	3.70
Insoluble	0.85	100	4.60
Ignition loss	2.20	125	5.25
	99.75	150	5.60
		172	6.00

Interesting figures regarding the influence of the temperature of calcination on the rate of hydration of light-burned magnesia are given by Campbell.[1] The material which he used was obtained by calcining magnesite of the following analysis on the basis of zero ignition loss:

MgO	90.78
CaO	3.96
SiO_2	2.53
Al_2O_3 and Fe_2O_3	2.70

For complete hydration this material required 44.59 per cent of its own weight of water.

In these tests the samples of magnesium oxide were kept barely covered with water. Those burned at 600°, 700° or 800° C were completely hydrated within three days. Between 1000° and 1100° C a change in the condition of the magnesium oxide occurs, which brings about a marked decrease in the rate of hydration. This effect is more marked as the temperature of calcining is increased. All samples calcined at not over 1100° C were completely hydrated in three months, while in the case of those heated to over 1200° C hydration was not complete after six years. The temperatures of calcining and percentages of complete hydration are given in the table below:

Temperature of calcining	Per cent—Complete hydration, years		
	1	3	6
1200° C	91.8	100.0	..
1300° C	64.0	76.2	83.5
1400° C	62.0	75.3	81.0
1450° C	51.2	61.7	70.3

[1] E. DeMille Campbell, "The Influence of the Temperature of Burning on the Rate of Hydration of Magnesium Oxide," *J. Ind. Eng. Chem.*, **1**, 665 (1909); **10**, 595 (1918).

Dead-burned magnesite has no plasticity; it absorbs neither moisture nor CO_2 from the air to any appreciable extent, but forms a hydrate and slakes rapidly to an almost impalpable powder when acted on by steam.[1] The resistance to slaking of commercial dead-burned magnesite, treated dolomites and burned dolomite has been studied at the Mellon Institute.[2] The increase in ignition loss of these materials, when moistened daily and exposed to the atmosphere at room temperature, is given in the following table and shown graphically in sketch 2. The analyses are given on the basis of zero ignition loss, although in each case there was a certain loss at the beginning of the test.

Material	A Washington magnesite	B Canadian magnesite	C Treated dolomite 1	D Treated dolomite 2	E Burned dolomite 1	F Burned dolomite 2
Silica	7.40	4.57	11.52	9.94	6.93	2.40
Alumina	2.34	2.08	3.93	1.88	4.03	1.00
Ferric oxide	4.83	7.89	4.43	4.58	1.73	1.22
Lime	3.13	18.96	48.15	49.19	51.64	56.61
Magnesia	81.93	66.66	32.26	35.18	35.75	38.69
Total	99.63	100.16	100.29	100.77	100.08	99.92
Loss on ignition at beginning of test, per cent	.02	.20	.08	.95	3.93	14.04
Ignition loss after 5 days	.48	.69	1.20	5.67	18.45	25.52
Ignition loss after 10 days	.96	1.52	1.62	8.35	20.00	26.30
Ignition loss after 15 days	1.24	1.94	2.39	10.10	23.30	33.00
Ignition loss after 20 days	1.36	1.92	3.01	10.92	23.66	29.70
Ignition loss after 25 days	2.09	2.65	6.30	12.00	24.33	25.99
Ignition loss after 30 days	2.54	3.25	4.63	14.99	24.67	30.81

It will be observed that in the case of both magnesite and dolomite the rate of slaking increases with the lime content, and that for the dolomites the rate increases as the sums of the iron oxide, silica and alumina contents decrease. The presence of these impurities, by facilitating sintering during the burning

[1] R. H. Youngman, "The Effect of Steam upon Magnesite Brick and Calcined Magnesite," *J. Ind. Eng. Chem.*, **6**, 1037 (1914); *Met. Chem. Eng.*, **12**, 620 (1914).

[2] McDowell and Howe, "Basic Refractories for the Open Hearth," *Trans. Am. Inst. Mining Eng.*, **55**, 291 (1919).

period, reduces, but does not overcome, the inherent tendency of lime to slake.

Fused magnesia is very slightly affected by CO_2 and H_2O at ordinary temperatures. A specimen containing 0.04 per cent CO_2 over which moist CO_2 gas was passed for 50 hours, contained only 0.42 per cent CO_2 at the end of the test.[1] Fitzgerald[2] describes another experiment in which ground "ordinary calcined" magnesite and "electrically calcined" magnesite were exposed to a current of moist CO_2 for 44 hours. At the end of that time the former showed 31.30 per cent increase in weight; the latter showed no increase.

Action of Carbon on Magnesia at High Temperatures.[3]—Various observers have noted that when magnesia and carbon are in contact at high temperatures, such as those of the electric furnace, the materials seem to shrink, the magnesia becomes deeply pitted if originally a smooth piece, and a black soot-like deposit appears on the interior walls of the cooler part of the furnace. This has been shown to be an intimate mixture of magnesia and carbon rather than a carbide. Magnesia is attacked even more severely by the carbides of iron, nickel and chromium, and by siloxicon and carborundum, than by carbon.

The generally accepted view is that the reaction is a reduction of the magnesia by the carbon according to the formula

$$\underset{\text{Solid}}{MgO} + \underset{\text{Solid}}{C} = \underset{\text{Vapor}}{Mg} + \underset{\text{Vapor}}{CO}$$

This action is reversible, being controlled principally by the temperature; the vapors of Mg and CO, formed in the hotter part of the furnace, are reduced to a mixture of solid MgO and C in the cooler parts.

The various observers are not in accord as to the temperature

[1] Fitzgerald and Bennie, *Trans. Am. Electrochem. Soc.*, **9**, 103 (1906).

[2] F. A. J. Fitzgerald, "Refractories," *Met. Chem. Eng.*, **10**, 129 (1912).

[3] O. P. Watts, "The Action of Carbon on Magnesia at High Temperatures," *Trans. Am. Electrochem. Soc.*, **11**, 279 (1907); Goodwin and Mailey, "Physical Properties of Fused Magnesia," *Ibid.*, **9**, 89 (1906); R. E. Slade, "Reduction of Magnesia by Carbon," *J. Chem. Soc.*, **93**, 327 (1908); P. Libeau, "Reduction of Magnesia by Carbon," *Compt. rend.*, **144**, 799 (1907).

at which this action begins. Northrup[1] observed a slight reaction between magnesia and graphite at 1450° C; Slade reports that the reaction with Acheson graphite begins at 1700° C, Kowalke and Grenfell[2] find that it begins slowly at 1950° C and becomes violent above 2030° C.

Magnesia cylinders containing 92.7 per cent MgO and 7.3 per cent SiO_2, when heated in a carbon resistance furnace and resting on a graphite block, lost weight at the following rates:[3]

Maximum temperature	Per cent loss in weight	
1500° C.	3.7	1 hour at maximum temperature
1800° C.	7.4	1 hour at maximum temperature
2000° C.	12.8	1 hour above 1950° C
2200° C.	27.0	1 hour at maximum temperature

The greater part of this loss was without doubt due to the MgO-C reaction, although direct volatization of MgO probably affected the figures.

Action of Phosphorus and Silicon at High Temperatures upon Dead-burned Magnesite.—McDowell and Howe[4] have studied the corrosive action of melts containing phosphorus and silicon upon basic crucibles. The crucibles were subjected, at 1350° C, to the action of molten mixtures of Fe_2O_3 + Fe_3P, and of Fe_2O_3 + FeSi, containing small percentages of P and Si. Fe_2O_3 alone was found not to corrode magnesite or dolomite at 1350° C. Therefore, any corrosive action of the melts upon the crucibles should be attributed chiefly to the action of phosphorus and silicon oxides formed by reduction of Fe_2O_3.

Analyses of the slags formed by melting these mixtures in basic crucibles revealed the fact that silica, lime, and magnesia went into solution in the melts, being taken from the walls of the crucibles; and led to the conclusion that the intensity of the

[1] E. F. Northrup, *Trans. Am. Electrochem. Soc.*, **27**, 234 (1915).

[2] Kowalke and Grenfell, "On the Temperature of Reaction between Acheson Graphite and Magnesia," *Ibid.*, **27**, 221 (1915).

[3] Kowalke and Hougen, *op. cit.*

[4] McDowell and Howe, "Basic Refractories for the Open Hearth," *Trans. Am. Inst. Mining Eng.*, **55**, 291 (1919); *Blast Furnace and Steel Plant*, **7**, 96 (1919).

action depended upon the amount of lime present in the materials of which the crucibles were made. Dead-burned magnesite low in lime was least effected, the dolomites were affected most easily, and a high-lime magnesite assumed an intermediate position.

TYPICAL PARTIAL ANALYSES OF SLAGS FROM CRUCIBLE TESTS, SHOWING RELATIVE PROPORTIONS OF OXIDES DISSOLVED FROM WALLS OF CRUCIBLES AT 1350° C BY TWO DIFFERENT MELTS

	High P melt, 6.1 per cent P		High Si melt, 5.2 per cent Si	
Oxide	Crucibles made from dead-burned magnesite containing 3 per cent CaO	Crucibles made from dead-burned magnesite containing 18 per cent CaO	Crucibles made from dead-burned magnesite containing 3 per cent CaO	Crucibles made from dead-burned magnesite containing 18 per cent CaO
SiO_2, per cent.....	0.18	0.46	...	..
CaO.....	.08	.26	Trace	0.33
MgO.....	.96	2.13	0.81	3.58
Total.....	1.22	2.85	.81	3.91
Ratio.....	1.0	2.3	1.0	4.8

PART V. PROPERTIES OF MAGNESIA BRICK

Properties in General.—Magnesia brick naturally have many properties in common with dead-burned magnesite, from which they are made; data given in the preceding pages which apply to both will not be repeated. Their chief value lies in their chemically basic character and high refractoriness; their greatest disadvantages are their sensitiveness to rapid changes in temperature, and their inability to support heavy loads at high temperatures.

Ordinary commercial brick are reddish to dark brown or black; special brick made from amorphous magnesite such as the Grecian, are from cream to buff in color. Both give a clear ring when struck; they are heavier than fire-clay or silica brick and in the cold condition are harder and much stronger, but when hot are considerably weaker than silica brick. The weight of a standard 9-inch brick, 9 by $4^1/_2$ by $2^1/_2$ inches, varies from 9.5 to 10 pounds.

Kanolt[1] in 1912 determined the fusion point of an American

[1] C. W. Kanolt, "Melting Points of Firebrick," U. S. Bureau of Standards, *Tech. Paper* 10 (1912).

magnesite brick, undoubtedly manufactured from Austrian material. The melting point, taken as the lowest temperature at which a small piece of brick could be distinctly seen to flow, was found to be 2165° C. This value compares with 1710° C for fire-clay or silica brick, and 2050° C for chrome brick. Magnesia brick of the usual dark color, and containing several per cent of iron oxide, become light in color after a few minutes heating near the melting point because of volatilization of the iron.

Magnesia brick should be stored in a dry place and carefully protected from the action of steam, which causes them to disintegrate. While hot they should not come in contact with water or cold air, nor should they be subjected to rapid temperature changes, as under these conditions they will shatter and spall.

The chemical composition of the brick is the same as that of the dead-burned magnesite from which they are made; this has been discussed in the preceding pages. Brick low in iron oxide and high in MgO are more difficult to make than the usual commercial product, and are not so strong unless burned at an exceedingly high temperature. The analysis of a special brick of this character is as follows:

MgO	89.10
Al_2O_3	1.15
Fe_2O_3	1.38
CaO	3.30
SiO_2	4.88

Specific Gravity.—The bulk specific gravity of magnesia brick is 2.60 to 2.75; the true specific gravity is 3.44 to 3.60, averaging about 3.52. A relationship seems to exist between the specific gravity and certain other properties, such as thermal conductivity, thermal expansion, chemical activity, and tendency to spall. This is to be expected, since a high specific gravity indicates a high proportion of periclase (density 3.67), many of whose properties are very different from those of the amorphous or low specific gravity form of MgO (density about 3.2). A high specific gravity indicates that the material is fully shrunk and that its chemical activity is weak as compared with that of amorphous magnesia.

Mellor[1] attributes the tendency of magnesia brick to crack and spall at high temperatures largely to the shrinkage accompanying the transformation of amorphous magnesia to periclase. However, there should be little, if any, spalling from this cause with bricks manufactured from magnesite which has been thoroughly dead-burned.

The porosity of magnesia brick averages from 24 to 30 per cent, but may be somewhat higher or lower than these figures, depending upon the method of manufacture. The possible influence of this factor upon other properties should always be considered in making physical determinations. Low porosity is desirable where brick is to be used in contact with slag, in order to minimize slag penetration. As pointed out by Simonis[2] the thermal conductivity is affected by the porosity. Mellor[3] is of the opinion that high porosity facilitates spalling by permitting excessive shrinkage at high temperatures; however, American experience seems to justify the conclusion that under most conditions a porous brick spalls less than a dense one.

Crushing Strength.—Magnesia bricks are much stronger in the cold condition than o her refractory bricks, a fact to be explained, in part at least, by their high flux content and high temperature of burning. For materials of American manufacture, the crushing strength of magnesia brick on flat ranges from 5000 to 8600 lbs. per sq. in.; that of first quality fire-clay brick from 1600 to 3500; that of silica brick averages 2600. The strength on edge and on end will in each case average 30 to 40 per cent less than these figures.

While very strong when cold, magnesia brick will not sustain a heavy load at high temperatures. Le Chatelier and Bogitch[4] state that the brick which they have tested all show an abrupt decrease in hot crushing strength at temperatures depending on

[1] J. W. Mellor, "Spalling of Magnesite Brick," *Trans. Ceram. Soc.* (*Eng.*), **16**, 85 (1916–1917); *Eng. Mining J.*, **104**, 229 (1917).

[2] M. Simonis, "Contribution to the Heat Conductivity of Firebrick," *Sprechsaal*, **41**, 547 (1908).

[3] *Op. cit.*

[4] Le Chatelier and Bogitch, "The Refractory Properties of Magnesia," *Trans. Ceram. Soc.* (*Eng.*), **17**, Pt. I, 18 (1917–1918).

their degree of purity. With one brick this occurred between 1300° and 1400° C; while with a purer one it took place between 1500° and 1600° C.

G. H. Brown[1] found that brick made of Austrian magnesite, set on end and heated, with a constant load of 50 pounds per square inch, failed suddenly at 1550° C with no previous evidence of contraction or softening. The brick sheared off diagonally into two parts much like a break resulting from a cold crushing test. Chrome brick, under the same conditions, failed suddenly at 1450° C.

Brick made from Washington magnesite will shear at temperatures from 1410° C to 1555° C, depending upon the composition and treatment of the crude material.[2] The lime content has a very marked effect upon the behavior of the brick in the load test. This has been shown by heating two bricks of the analyses given below at the rate of 250° C temperature increase per hour, under constant pressure of 25 pounds per square inch applied to the ends. The brick, which contained 15 per cent of lime, began to soften at 1300° C, and had compressed 12.5 per cent of its original length by the time 1475° C was reached. The brick with only 3.2 per cent of lime did not soften nor compress appreciably, and sheared suddenly at 1555° C.

ANALYSES OF BRICKS SUBJECTED TO LOAD TESTS AT HIGH TEMPERATURES

	Washington magnesite	Canadian magnesite
MgO	82.40	70.84
CaO	3.18	15.05
SiO_2	7.26	5.72
R_2O_3	7.09	7.94

According to Mellor and Emory[3] magnesia brick whose fusion point was above 1920° C, when heated under a load of 50 pounds per square inch, first deformed slightly and suddenly collapsed at about 1500° C. Chrome brick behaved in the same manner

[1] G. H. Brown, "Load Tests on Magnesia, Chrome and Silica Brick," *Trans. Am. Ceram. Soc.*, **14**, 391 (1912).

[2] McDowell and Howe, "Basic Refractories for the Open Hearth," *Trans. Am. Inst. Mining Eng.*, **55**, 291 (1919).

[3] Mellor and Emory, "Effect of Load on the Refractoriness of Firebricks," *Gas J.*, **142**, 478 (1918).

at about 1400° C. Zirconia brick, under a load of 25 pounds per square inch, "squatted" at about 1600° C, and under 75 pounds per square inch, at 1420° C. As determined by Le Chatelier,[1] silica brick made in America have a crushing strength of over 500 pounds per square inch at 1500° C.

Specific Heat of Magnesia Brick.[2]—The specific heat of brick composed of 88.85 MgO, 0.35 CaO, 0.20 SiO_2, 9.31 Fe_2O_3, and 0.17 Al_2O_3 is given by E. Heyn as follows:

t °C	True specific heat at t °C	Mean specific heat between 25° C and t °C
0	0.208	...
100	...	0.220
200	.253	.233
400	.275	.250
600	.290	.260
800	.316	.269
1000	.324	.278
1100	.332	.282
1200	.340	.287
1300	.349	.291

According to Steger,[3] the mean specific heat between 20° C and 200° C of magnesia brick containing 84.5 per cent MgO, was 0.225. The values in the table are considerably higher than the figures for fire-clay brick, the specific heat of which corresponds to the following formula:[4]

Specific heat = $0.193 + 0.0_46t$, where t is expressed in degrees centigrade.

Thermal Conductivity.[5]—While the thermal conductivity of magnesia brick is generally recognized to be high as compared

[1] Le Chatelier and Bogitch, "The Manufacture of Silica Brick," *Trans. Am. Inst. Mining Eng.*, **60**, 134 (1919); *Compt. rend.*, **165**, 742 (1917).

[2] E. Heyn, "Thermal Conductivity of Refractory Building Materials," *Mitteilungen a. d. kgl. Material-prüfungsamt*, **32**, 185 (1914).

[3] W. Steger, "The Specific Heat of Refractory Materials," *Silikat-Z.* **2**, 203 (1914).

[4] Wilson, Holdcroft and Mellor, "Specific Heats of Firebrick at High Temperatures," *Trans. Ceram. Soc. (Eng.)*, **12**, 279 (1912–1913).

[5] E. Griffiths, "The Thermal Conductivity of Materials Employed in Furnace Construction," *Trans. Faraday Soc.*, **12**, 193 (1917). Hutton and Beard, "Notes on Heat Insulation," *Ibid.*, **1**, 264 (1905).

with that of the other common refractories, considerable difference exists in the results reported by various observers. In a few cases these results obviously disagree with known facts; in others, it is possible that differences in the methods used, as well as variations in porosity, specific gravity and impurity content of the brick, may account for the lack of concordance in the

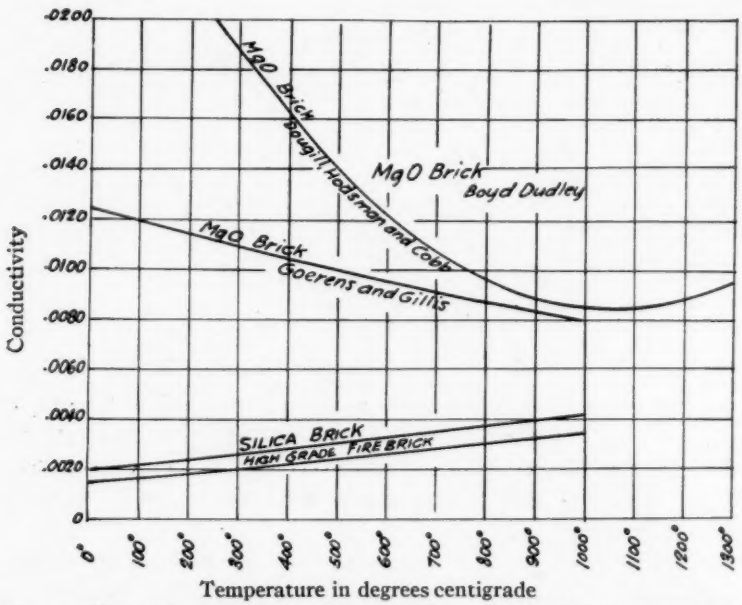


FIG. 2.—Thermal conductivity of refractories. Conductivity expressed in calories per 1° C temperature difference, per second, per square centimeter area, per centimeter thickness.

results. The conductivity seems to decrease with rise of temperature, contrary to that of silica and clay brick which are better conductors at high temperatures than at low.

The specimen studied by Boyd Dudley[1] (analysis: MgO 86.5, SiO_2 2.5, Fe_2O_3 7.0, Al_2O_3 0.5, and CaO 2.75; volume density 2.46) had a constant conductivity between 445° and 830° C, and a coefficient within that temperature range of 0.0135 calories per

[1] Boyd Dudley, "The Thermal Conductivity of Refractories," *Trans. Am. Electrochem. Soc.*, **27**, 285 (1915).

second, per sq. cm., per cm. thickness, per 1° C temperature difference. The same observer reports the mean conductivity between 0° C and 1000° C of "Star" silica brick to be 0.0031, and of Woodland clay brick 0.0025.

Goerens and Gillis[1] found the magnesia brick with which they experimented (analysis: MgO 86.42, SiO_2 2.66, Al_2O_3 6.47, Fe_2O_3 4.45, lime —; volume density 2.34; true density 3.53; porosity 34 per cent) to have a mean coefficient of conductivity between 100° and 200° C of 0.0117; between 0° and 1000° C of 0.100; and true conductivity at 1000° of 0.0080. Their results may be expressed approximately by the formula:

$\frac{K^\circ}{1000^\circ} = 0.0124 - 0.0_326(t_1 + t_2) + 0.0_92(t_1 + t_2)$,[2] where K is the mean coefficient between any two temperatures t_1 and t_2.

Dougill, Hodsman and Cobb,[2] working with a fine grained magnesia brick low in iron and branded "Mabor" (analysis: MgO 92.1, SiO_2 5.0, Al_2O_3 0.4, Fe_2O_3 1.6, CaO 1.7; volume density 2.40; true density 3.51, porosity 31.4 per cent) found that the conductivity decreased rapidly with rising temperatures up to a certain point, and that it was represented closely by the formula:

$K = 0.0285 - 0.0_4379^t + 0.0_7179t^2$ at any temperature t between 270° C and 1370° C.

According to this formula, the mean conductivity between 0° and 1000° C (by integration) is 0.0155; the true conductivity at 1000° C is 0.0085.

Electrical Resistivity of Magnesia Brick.—It is natural that interest in the electrical resistivity of refractories, especially those made of magnesia, has increased with the more general industrial application of the electric furnace, yet very little information on the subject is available. Stansfield, MacLeod and McMahon[3] have compared the resistivity at high temperatures of silica, Austrian magnesia and chrome brick made in America, and firebrick from Caledonia. They state that the probable error of

[1] Goerens and Gillis, "The Thermal Conductivity of Refractory Materials," *Ferrum*, **12**, 1, 17 (1915).

[2] Dougill, Hodsman and Cobb, "Thermal Conductivity of Refractory Materials," *J. Soc. Chem. Ind.*, **34**, 465 (1915).

[3] Stansfield, MacLeod and McMahon, "The Electrical Resistivity of Firebrick at High Temperatures," *Trans. Am. Electrochem. Soc.*, **22**, 89 (1912).

their determinations is less than five or ten per cent for readings under 6,000 ohms, increasing to a maximum probable error of 25 per cent at 21,000 ohms; also that the results for chrome brick are subject to correction.

ELECTRICAL RESISTIVITY IN OHMS PER CM³

Temperature °C	Magnesia brick	Chrome brick	Silica brick	Fire-brick
600	...	...	...	21,000
700	...	...	...	17,000
800	...	2,800	...	13,000
900	...	760	...	9,000
1000	...	420	...	6,600
1100	...	430	...	4,400
1200	...	450	...	2,300
1300	6,200	410	9,700	1,300
1400	420	320	2,400	690
1500	55	...	710	280
1550	30	...	22	60
1565	25	...	18	..

Thermal Expansion of Magnesia Brick.—Data from three sources[1] are available on this subject, and the close agreement in the figures given is unusual when the variety of raw materials involved and the difference in methods are considered. Not only do the three investigators check each other closely, but the results also justify the common practice in laying of allowing about $^{3}/_{16}$ inch per foot (or 1.56 per cent) for expansion.

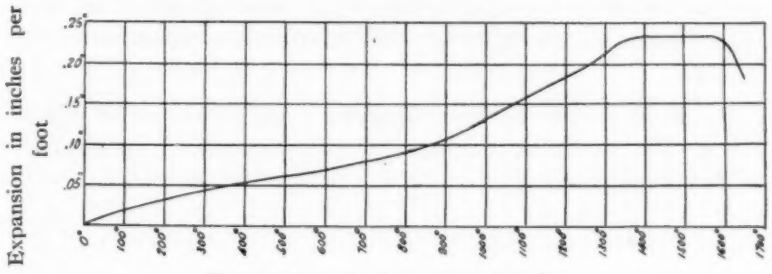
PER CENT LINEAR EXPANSION OF MAGNESIA BRICKS

Source of raw material	Observer	°C 200	400	600	800	1000	1200	1400	1600
Washington..	S. M. Phelps	..	..	..	1.04	..	..	1.95	..
Washington..	S. M. Phelps	..	..	..	.90	..	..	1.81	..
Austria.....	LeChatelier	0.21	0.55	0.85	1.10	..	..	..	..
Greece.....	LeChatelier	.25	.52	.79	1.02	..	..	..	..
Austria.....	R. H. H. Pierce	.25	.46	.57	.79	1.08	1.50	1.88	1.88
Average.....		.24	.51	.74	.97	1.08	1.50	1.88	1.88

The expansion curve of commercial brick made in America, as determined by Pierce, is shown in figure 3. He observed that expansion ceased at about 1350° C, and that contraction took place above 1600° C.

[1] R. H. H. Pierce, private notes, Harbison-Walker Refractories Co.; S. M. Phelps, private notes, Mellon Institute of Industrial Research.

Other observers have noticed that magnesia brick sometimes shows a permanent contraction after reheating to high temper-



Temperature in degrees centigrade

FIG. 3.—Thermal expansion of magnesia brick, made from Austrian magnesite.

atures. After reburning to the highest temperature of the porcelain kiln, certain brick made in Austria showed the following permanent shrinkage:

Reburn	Linear shrinkage per cent	Total linear shrinkage per cent
1	0.36	0.36
2	.31	.67
3	.13	.80
4	.08	.88

Mellor found that a British magnesia brick, of slightly lower true specific gravity than the average American product, showed a marked contraction on the heated end when subjected to the heat of the Rennerfelt electric furnace. Of the total contraction, 6 per cent was attributed to the shrinkage of the magnesia, and the remainder, 9.8 per cent, to the closing of the pore space.

Thermal Expansion of Magnesia Bricks under Pressure.—This data was obtained at the laboratories of the Mellon Institute by heating magnesia brick at the rate of 250° C per hour under a constant load. The total expansion of the brick, pressure rods, furnace, and so forth, was first noted and recorded. The incidental expansion of the furnace parts was obtained by subjecting silicon carbide brick to similar treatment and allowing for the known expansion of these bricks. This incidental expansion was subtracted from the total expansion and the remainder attributed to the magnesia brick.

Four magnesia brick showed an average linear expansion of 0.96 per cent at 800° C, and 1.94 per cent at 1200° C, under a pressure of 25 pounds per square inch. It will be observed that these figures do not differ appreciably from the expansion under no load.

Chemical Action Between Magnesia and Fire-clay or Silica Brick.—The fact that magnesia enters into chemical combination at high temperatures with fire-clay and silica refractories has been known for a long time. The reaction is less violent, and takes place at higher temperature, with silica brick than with fire-clay brick; hence, magnesia brick is often used in furnace walls in contact with the former, but should be separated from clay brick by a neutral course such as chrome. Bischof[1] observed that fireclay and magnesia react at a temperature estimated to be about 1600° C, with the formation of a very fluid gray slag which rapidly penetrates a fire-brick.

The subject has recently been studied in the following manner:[2] Small pats or discs of refractory material were made in semi-circular sections, separated by a thin joint of chrome. One section, which held standard pyrometric cones, consisted of fire-clay; the other section, in which chips of fire-brick or silica brick were placed, was made of dead-burned magnesite. The pats were placed on chrome pedestals and heated at such a rate that succeeding standard cones melted at three hour intervals. The results obtained are expressed in the following table:

REACTING TEMPERATURES BETWEEN MAGNESIA AND FIRE-CLAY OR SILICA BRICK

Material[3]	First quality fire-clay brick	Silica brick
Dead-burned magnesite containing 3 per cent CaO.....	Cone 20 (about 1530° C)	Cone 26 (about 1610° C)
Dead-burned magnesite containing 15 per cent CaO.....	Cone 18 (about 1490° C)	Cone 18 (about 1500° C)

[1] Bischof, "Magnesite Brick," *Oesterr. Z. Berg-Hüttenw.*, **41**, 27 (1893); *J. Iron Steel Inst.*, **49**, Pt. I, 212 (1893).

[2] McDowell and Howe, *op. cit.*

[3] Complete analyses given on page 222.

The temperatures indicated in the table as the fusion points of the pyrometric cones are those obtained by heating at a standard rate of temperature increase; in this test the rate of heating was much slower, and it is probable that fusion of the cones took place 80° C to 90° C lower than the figures given.

A violent reaction occurred between high grade magnesite and fire-brick at cone 20, with the formation of a thin liquid. The behavior of the silica brick chips was remarkable in that they seemed to be unaltered by whatever action had taken place, while they had cut deeply into the magnesite, creating a small cavity.

PART VI. MICROSCOPIC STUDIES

It has been shown in the preceding pages that caustic burned magnesia is composed essentially of amorphous magnesia,[1] while the dead-burned material is largely periclase. Pure amorphous magnesia probably begins to be altered to periclase, the crystalline form of MgO, at 1200° C or slightly lower, but with extreme slowness; the higher temperature the more rapidly conversion takes place. In the commercial production of dead-burned magnesite, it is found that the temperature necessary depends upon the duration of the heating, the size of the lumps, and the texture and composition of the crude material. Certain impurities are known to have a catalytic effect in hastening the change; it has been observed that a magnesite high in iron, such as the Austrian, can be dead-burned at 1450° to 1500° C, while one low in iron and other impurities requires a temperature of 1600° to 1700° C, or even higher.

Kowalke and Hougen,[2] have studied the effect of varying the temperature of burning upon the microscopic texture of cylinders made of pure magnesia, mixed with $7^1/_2$ per cent SiO_2, molded at 1500 pounds per square inch, baked in an electric furnace. Periclase and forsterite ($2MgO \cdot SiO_2$) were identified in these specimens. Very little forsterite was formed at temperatures below 1500° C.; it appeared first on the boundaries of the peri-

[1] See page 211.

[2] Kowalke and Hougen, "Crushing Strength of Magnesia-Silica Mixtures at High Temperatures," *Trans. Am. Electrochem. Soc.*, **33**, 215 (1918).

clase grains. As the temperature of burning was raised to between 1700° and 1800° C the forsterite crystals increased rapidly in number and size, and finally united to form a complete envelope about the periclase crystals. In specimens burned above 2000° C this envelope did not exist, but the forsterite had collected to form separate crystals; such specimens had a lower hot crushing strength than those in which the forsterite surrounded the periclase grains. The forsterite evidently acts as a bond to hold the periclase crystals together, and loss of strength occurs at a temperature which causes softening of the forsterite, or of the MgO-forsterite eutectic.

F. Cornu[1] found that Austrian magnesite brick consist essentially of periclase crystals with clear outer rims, but with their central portions filled with very minute black opaque particles having well developed cubic cleavage and identified as magnesioferrite ($MgO \cdot Fe_2O_3$). The later work of Cronshaw[2] indicates that this indentification was probably correct. Cornu observed between the periclase crystals, a dark to yellowish brown vitreous cement formed from the impurities in the magnesite. This cement he considered to be a CaO-Al_2O_3-SiO_2 glass, and estimated its amount as 6 per cent. It seems to have been observed by no other worker.

Scott[3] has pointed out that British magnesite brick show two well defined types of structure. The first is characteristic of brick containing iron oxide as the main impurity, the second of those in which the main impurities are silica and lime. Both forms of crystallization are sometimes found in the same brick, but one or the other usually predominates, depending on the character of the impurities.

Thin sections of type one consist essentially of polygonal crystals of periclase, forming a reticulate aggregate, and often with

[1] F. Cornu, "On the Composition of Magnesia Brick, Especially their Content of Periclase," *Z. prakt. Geol.*, **16**, 449 (1908); quoted by F. Redlich in Doelter's "Handbuch der Mineral Chemie," **1**, 253 (1912).

[2] H. B. Cronshaw, "A Curious Mineral Occurring in a Magnesia Brick," *Trans. Ceram. Soc. (Eng.)*, **16**, Pt. I, 101 (1916–17).

[3] A. Scott, "Note on the Microstructure of Magnesite Bricks," *Ibid.*, **17**, Pt. II, 475 (1917–18).

well-defined cleavage. The periclase crystals contain inclusions of small, dark grains of magnesioferrite, and are usually brownish to red. This color was believed to be caused by iron oxide or by a ferrate of magnesium in solid solution with the periclase. The impurities other than the iron crystallize mainly as silicates, forming doubly refracting areas between the periclase grains.

In type two the periclase occurs in the form of rounded grains, extremely variable in size, and very rarely containing magnesioferrite inclusions. The polygonal structure of type one is absent, and adjacent periclase granules are usually separated by layers of impurities. These form a ground mass of variable composition, sometimes showing traces of glass but generally crystalline. Lath-shaped crystals of high double refractions, apparently forsterite, may be observed; a mineral resembling monticellite is more common.

Scott believes that brick showing the first type of crystallization is more refractory than that showing the second, owing to the higher percentage of silicates in the latter, and observes that a brick containing appreciable quantities of monticellite would have a molten ground-mass at furnace temperatures.

According to W. Donald[1] the formation of periclase occurs more rapidly and uniformly the more uniformly the impurity is distributed throughout the magnesite; the impurities should not merely coat the larger fragments but should interpenetrate them. Very pure magnesite of the dense variety, calcined in the electric furnace, was studied under the microscope. It was observed that each grain was completely transformed to periclase at the outer edges where it was in contact with impurities; next to this was a fine grained band into which crystallization was penetrating, and the interior of the grain consisted of a core of amorphous magnesia. Styrian brick from Veitsch were found to have a very uniform section with a homogeneous ground-mass. The larger particles did not exceed one-eighth inch in diameter and consisted of 150 to 180 small periclase crystals whose borders were separated by thin films of impurities. In British brick made

[1] W. Donald, "Magnesite and Magnesite Bricks," *Trans. Ceram. Soc.* (*Eng.*), **17**, Pt. II, 494, 521 (1917–18).

from Grecian magnesite the impurities were seen to surround and coat the fragments, but not to penetrate them.

C. R. Fettke[1] has compared the microscopic structure of a brick made from Washington magnesite with that of one manufactured before the war from Austrian material. The former was made from magnesite which had been dead-burned in a rotary kiln with the addition of sufficient iron oxide to bring the R_2O_3

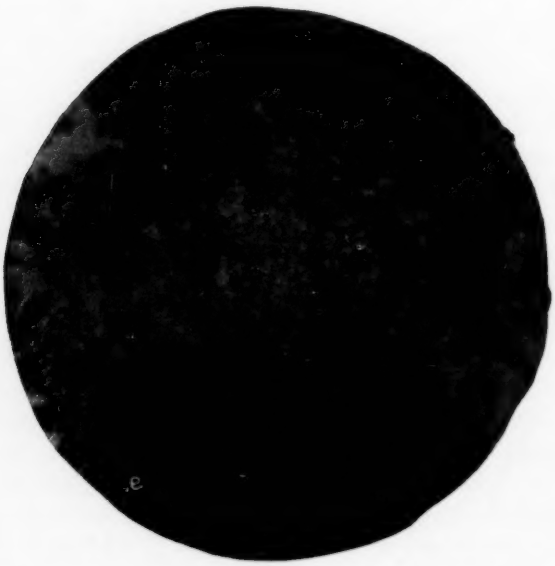


FIG. 4.—Photomicrograph of brick made from Washington magnesite (Fettke) Ordinary light. × 104.

content to 7.0 per cent. Under the miscroscope the larger fragments in the brick can be readily distinguished from the finer grained matrix. A few of these fragments are 1.0 mm. in diameter, but the average are under 0.6 mm. The individual particles, both of the larger fragments and of the matrix, consist of granules averaging under 0.05 mm. in diameter, of yellowish brown color, occasionally with cubic cleavage; these granules were considered to be periclase, colored by iron oxide held in solid solution. Some

[1] C. R. Fettke, unpublished paper, 1918.

of the granules are free from inclusions, but a large proportion are rendered cloudy to nearly opaque by the presence of numerous inclusions too fine to be determined, but which are probably magnesioferrite. In the fragments the periclase granules interlock well, usually with only thin films of colorless silicates between them, although in a small proportion of the particles the percentage of silicates is high. In the matrix the silicates are more

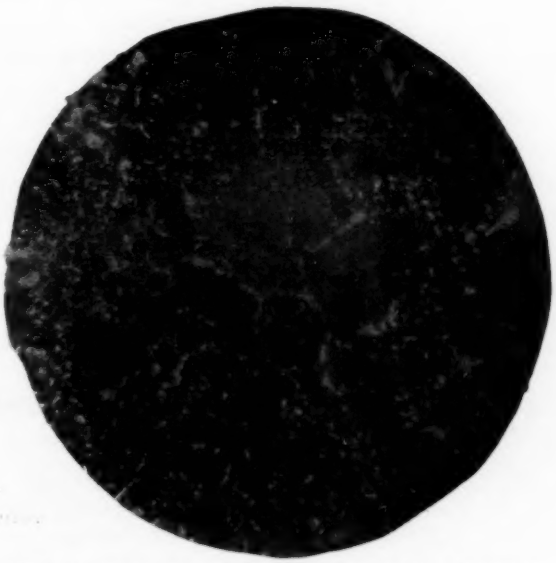


FIG. 5.—Photomicrograph of brick made from Austrian magnesite (Fettke) Ordinary light. × 104

abundant between the periclase grains than in the fragments, and they are occasionally concentrated in bunches. In a few cases the periclase appears to have reacted with the impurities, as the borders of some of the grains are doubly refracting. The silicates have the optical properties of the olivine group of minerals, members of which are monticellite, forsterite and olivine. No free iron oxide could be identified in the section.

The brick made of Austrian magnesite was slightly coarser in texture than the one just described, and some of the larger frag-

ments in the section have a diameter of 1.2 mm. Particles of both the fragments and matrix are composed of periclase granules, but the borders of these are not as distinct as in the brick of Washington material. In the fragments the granules reach 0.08 mm. in diameter, but they are smaller in the matrix. They are so full of minute dark inclusions (magnesioferrite?) that they are nearly opaque. In the fragments the periclase grains interlock well and silicates are practically absent. The granules of the matrix have a tendency toward roundness and are usually separated by silicates. In this brick the silicates are confined largely to the matrix, they are not so abundant as in the brick of Washington magnesite, the size of the silicate crystals is smaller, they are more uniformly distributed throughout the matrix, and they interlock better with the periclase crystals.

In a brick made from Californian magnesite, R. D. Pike[1] observed that the outer edge of the periclase grains was often clear, while the interior was rendered cloudy by numerous small inclusions. These were typical skeleton crystals, some of which were black and opaque, others reddish brown and translucent.

Mineralogical Note—Properties of Periclase, Magnesioferrite and the Olivine Group of Minerals[2]

PERICLASE: Composition, MgO = 100 per cent. Isometric, in cubes and octahedrons; usually colorless to grayish; cubic cleavage perfect. Hardness nearly 6; specific gravity 3.674; melting point 2800° C.

MAGNESIOFERRITE: Composition, $MgO \cdot Fe_2O_3$ = MgO 20 per cent Fe_2O_3 80 per cent. Isometric, in octahedrons, with and without truncated edges; opaque. In luster, color and streak it resembles magnetite and is strongly magnetic; hardness 6 to $6\frac{1}{2}$; specific gravity 4.57 to 4.65.

FORSTERITE: Composition, $2MgO \cdot SiO_2$ = MgO 57.1 per cent, SiO_2 42.9 per cent. Orthorhombic; color white, grayish, greenish. Hardness 6 to 7; specific gravity 3.21 to 3.33. Melting point 1890° C. No sharp line can be drawn between forsterite and chrysolite.

CHRYSOLITE (OLIVINE): Composition, $2(MgFe)O \cdot SiO_2$. Olivine grades into forsterite on the one side and fayalite ($2FeO \cdot SiO_2$) on the other; there is no sharp line of distinction on either side.

[1] R. D. Pike, Northwest Magnesite Co., private communication.

[2] Dana, "System of Mineralogy."

ANALYSIS

	MgO	FeO	SiO_2
MgFe = 9:1	49.2	9.8	41.0
MgFe = 5:1	44.3	15.9	39.8
MgFe = 3:1	38.5	23.0	38.5
MgFe = 2:1	33.1	29.7	37.2

Orthorhombic; color usually green; hardness 6.5 to 7; specific gravity 3.27 to 3.57, increasing with the amount of iron present.

MONTICELLITE: Composition, $CaO \cdot MgO \cdot SiO_2$ = CaO 35.9 per cent, MgO 25.6 per cent, SiO_2 38.5 per cent; iron replaces part of the magnesium. Orthorhombic; colorless, yellowish and greenish gray; translucent. Hardness 5 to $5^1/_2$; specific gravity 3.03 to 3.25.

Discussion.—The microscopic studies described above indicate that probably during the burning of the brick the iron oxide combines very slightly, if at all, with the other impurities of the magnesite, but that it enters into solid solution with the periclase crystals, and also combines with magnesia to form magnesioferrite. The latter separates out as minute inclusions within the periclase granules. The great value of the proper proportion of iron in magnesite evidently lies in its catalytic effect in hastening the formation of periclase.

Most magnesia brick contain alumina up to 1 or 2 per cent. The role played by this impurity is not definitely known, although there is reason to believe that alumina lowers the melting point of the bonding ground-mass of the brick, since clay, hydrated aluminum silicate, exerts a strong fluxing action on commercial magnesite when mixed with it even in small proportions.

The lime and silica impurities form silicate minerals evidently of the olivine group by combining with the necessary amount of magnesia. Forsterite, $2MgO \cdot SiO_2$, has been identified under the microscope by several observers. These silicates surround the periclase crystals and bond them together, and in small amounts may be necessary for the production of a well-bonded brick. To what extent they are needed is not clear, however, as it seems possible that if these impurities were almost entirely lacking, and sufficient iron oxide were present, a strong bond might be attained at kiln temperatures through interlocking of the periclase crys-

tals. J. B. Ferguson[1] has found that pure calcined magnesia powder, containing only 0.44 per cent silica, when heated for some hours in a small electric furnace at 1600° to 1700° C, formed a dense cake with considerable mechanical strength. A microscopic examination disclosed no bonding material; only interlocking periclase crystals, with less than $^1/_2$ per cent of forsterite, could be identified. However, Kowalke and Hougen[2] have shown that cylinders made of MgO-SiO_2 mixtures are stronger at high temperatures with $7^1/_2$ per cent silica than with lower or higher amounts. It is interesting to note that in these tests the temperature of failure under a load of 66.5 pounds per square inch for mixtures containing 6 to 12 per cent SiO_2 varied from 1830° to 1870° C, temperatures very close to the melting point of the magnesia-forsterite eutectic.

The melting point of the magnesia-forsterite eutectic is 1850° C, and of the magnesia-lime eutectic 2300° C. In the ternary system CaO–MgO–SiO_2, the melting points and composition of the quintuple points bounding the forsterite field, and of one common to the periclase and monticellite fields, are as follows:[3]

Composition			Melting point
MgO	CaO	SiO_2	
22.3	37.3	40.3	1498° C
26.4	32.1	41.5	1502° C
22.3	33.3	44.4	1436° C
20.2	29.8	50.0	1357° C

It is evident from the figures given that when silica and lime are both present the melting points are much lower than when one or the other is absent; and that the relative proportions of lime and silica have a decided effect upon the fusibility. It is probable that in the burning of magnesia brick silicates whose melting points approximate the above figures are formed between

[1] J. B. Ferguson, "Note on the Sintering of Magnesia," *J. Am. Ceram. Soc.*, **1**, 439 (1918).

[2] O. L. Kowalke and O. A. Hougen, "Crushing Strengths of Magnesia Silica Mixtures at High Temperatures," *Trans. Am. Electrochem. Soc.*, **33**, 215 (1918).

[3] Ferguson and Merwin, "The Ternary System CaO–MgO–SiO_2," *Am. J. Sci.*, **48**, 81 (1919).

the periclase grains. At furnace temperatures such silicates would be molten and the brick would then consist of periclase crystals, surrounded by a viscous mass of molten silicates saturated with dissolved magnesia. The amount of the viscous groundmass would depend upon the quantity and relative proportions of lime and silica in the brick. This view is in accordance with the fact that magnesia bricks, although strong when cold, lose their strength and seem lacking in bond at high temperatures; and that when lime and silica are present in excessive amounts, their refractoriness and load carrying capacity are greatly reduced. Le Chatelier and Bogitch[1] reached the conclusion that the brick when heated behave "as if the impurities melt suddenly at a certain temperature, leaving the magnesia grains isolated in a molten magma. They are then in the same condition as wet sand and possess only a very weak mechanical resistance."

The field for investigation of the properties of dead-burned magnesite and magnesia brick, and of the possibilities of improving their commercial value, offers a number of attractive problems. The influence of texture and composition of the raw magnesite, and the effect of added impurities upon the properties of the burned product, are not thoroughly understood. How the change from amorphous magnesia to periclase crystals may be brought about most economically and completely, and the crystals bonded together to form a brick which will be strong at furnace temperatures, with minimum shrinkage and tendency to spall, are questions deserving much careful study.

Harbison-Walker Refractories Co., Pittsburgh, Pa.
Mellon Institute of Industrial Research, Pittsburgh, Pa.

A SELECT BIBLIOGRAPHY OF MAGNESITE AND MAGNESITE BRICK[2]

1873

The Crystalline Magnesite of the Northern Alps, J. Rumpf, *Mineralog. petrog. Mitt.*, **1**, 263 (1873).

[1] Le Chatelier and Bogitch, "The Refractory Properties of Magnesia," *Trans. Ceram. Soc.* (*Eng.*), **17**, Pt. II, 18 (1917–1918).

[2] In the preparation of this bibliography the standard journal abbreviations of the American Chemical Society (see *C. A.*, Dec. 20, 1915) have been used. Volume numbers are given in bold-faced type. For convenience of reference, the citations are arranged in chronological order.

For the most part references to the occurrence of magnesite have been

1882

Basic Open-Hearth Steel Process at Alexandrowsky Works, St. Petersburg, C. T. Tellander, *Stahl u. Eisen*, **2**, 599 (1882); *J. Iron Steel Inst.*, **30**, 465 (1883).

1885

Basic Refractory Materials, T. Egleston, *Trans. Am. Inst. Mining Eng.*, **14**, 455 (1885–6).

1886

Refractory Materials, Anon., *J. Iron Steel Inst.*, **36**, 892 (1886).

Magnesia *vs.* Dolomite as Basic Refractory Materials, M. Zyromski, *Compt. rend.*, **51**, 96 (1886); *Am. Mfr.*, **39**, 9 (1886); *J. Iron Steel Inst.*, **36**, 89 (1886).

1887

Magnesite and Its Use as a Basic Refractory, K. Sorge, *Stahl u. Eisen*, **7**, 850 (1887).

Recent Improvements in Open-Hearth Practice, A. E. Hunt, *Trans. Am. Inst. Mining Eng.*, **16**, 718 (1887–8).

1890

Magnesite Linings in Basic Open-Hearth Furnaces, Leo, *Stahl u. Eisen*, **10**, 222 (1890).

The Basic Open-Hearth Process, N. Kjellberg, *Iron Age*, **45**, 671 (1890); *J. Iron Steel Inst.*, **43**, 315 (1890).

1892

Magnesite, F. Bleichsteiner, *Oesterr. Z. Berg-Hüttenw.*, **40**, 355 (1892).

1893

Importance of Magnesite for Basic Lining of Soft Steel Furnaces, H. Wedding, *Stahl u. Eisen*, **13**, 279 (1893); *J. Iron Steel Inst.*, **49**, 208 (1893).

Magnesia Bricks, C. Bischof, *Oesterr. Z. Berg-Hüttenw.*, **41**, 27 (1893); *J. Iron Steel Inst.*, **49**, 208 (1893); *Stahl u. Eisen*, **13**, 218 (1893).

Magnesite as a Refractory Material, Anon., *J. Soc. Chem. Ind.*, **12**, 961 (1893).

Refractory Materials, Anon., *J. Iron Steel Inst.*, **49**, 208 (1893).

Magnesia Firebricks, Anon., *Engineering (London)*, **53**, 452 (1893).

1899

Magnesite, D. E. McGinley, *Eng. Mining J.*, **68**, 665 (1899).

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purposely omitted, although a few of the more important journal citations are included. For detailed information regarding the geochemical aspects of this subject the following works should be consulted: Doelters "Handbüch fur Mineral Chemie," Steinkopf Press, Dresden, 1912 and Clarke's "Data of Geochemistry," 3rd ed., 1916 (*Bull.* **616**, U. S. Geol. Survey). A valuable index to the magnesite deposits of the United States is contained in *Bull.* **624** of the U. S. Geol. Survey. A similar index of more general scope has been prepared by Thomas Crook in "Magnesite as a Raw Material," *Trans. Ceram. Soc. (Eng.)*, **18**, 67 (1918–19).

1900

Dolomites Suitable for the Basic Open-Hearth Process, Anon., *Tonind.-Ztg.*, **24,** 638 (1900).

Magnesite, E. Schmatolla, *Ibid.*, **24,** 1469 (1900).

1903

Magnesite—Its Uses and Value, C. C. Schnatterbach, *Eng. Mining J.*, **73,** 55 (1903).

Hungarian Magnesite Deposits, H. Weiss, *Iron Age*, **71,** 20 (1903).

1905

Magnesite, C. Schimm, *Tonind.-Ztg.*, **29,** 1968 (1905); *Stahl u. Eisen* **26,** 303 (1906).

Crucibles, Tiles, Muffles and Other Technical Apparatus from Pure Magnesia, Anon., *Z. Elektrochem.*, **11,** 581 (1905).

Notes on Heat Insulation, Particularly with Regard to Materials Used in Furnace Construction, R. S. Hutton and J. R. Beard, *Proc. Faraday Soc.*, **1,** 266 (1905); *J. Soc. Chem. Ind.*, **24,** 802 (1905).

Heat Insulating Qualities of Refractory Materials, F. A. G. Fitzgerald, *Met. Chem. Eng.*, **3,** 291 (1905).

Magnesia for Furnace Linings, Anon., *Met. Chem. Eng.*, **3,** 140 (1905); discussion by W. M. Johnson, *Ibid.*, **214**.

The Dissociation of the Carbonates of the Alkaline Earths and Magnesium, O. Brill, *Z. anorg. Chem.*, **45,** 275 (1905).

1906

Physical Properties of Fused Magnesia, H. M. Goodwin and R. D. Mailey, *Trans. Am. Electrochem. Soc.*, **9,** 89 (1906); *Met. Chem. Eng.*, **4,** 216 (1906); *Phys. Rev.*, **23,** 22 (1907).

1907

The Action of Carbon on Magnesia at High Temperatures, O. P. Watts, *Trans. Am. Electrochem. Soc.*, **11,** 279 (1907); *Chem. Ztg.*, **31,** 739 (1907).

Experiments with Magnesia, M. Ogan, *Trans. Am. Ceram. Soc.*, **8,** 364 (1907).

Plant of Osnabruck, K. Gerson, *Stahl u. Eisen*, **27,** 1066 (1907).

Reduction of Magnesia by Carbon, P. Libeau, *Compt. rend.*, **144,** 799 (1907); *Rev. electrochim.*, **1,** 159 (1907).

1908

Chrome and Magnesite as Basic Refractories, F. T. Havard, *Eng. Mining J.*, **86,** 802 (1908); *Met. Chem. Eng.*, **6,** 504 (1908).

Magnesite, Robt. Scherer, published by A. Hartleben, Vienna-Leipzig (1908).

The Magnesite Deposits of California, Frank L. Hess, U. S. Geol. Surv., *Bull.* **355**.

On the Mineralogical Composition of Magnesite Bricks, Especially. Their Content of Periclase, F. Cornu, *Centr. Mineral Geol. (Leoben)* (1908); *Z. prakt Geol.*, **16,** 449 (1908).

Reduction of Magnesia by Carbon, R. E. Slade, *J. Chem. Soc.*, **93,** 327 (1908).

1909

Magnesite Deposits in Gömör, Hungary, Anon., *Stahl u. Eisen*, **29,** 294 (1909).

Indian Magnesite Industry, H. H. Davis, *J. Soc. Chem. Ind.*, **28,** 503 (1909); *Eng. Mining J.*, **87,** 1075 (1909).

Binary Systems of Alumina with Silica, Lime and Magnesia, E. S. Shepherd and G. A. Rankin, *Am. J. Sci.*, **28,** 293 (1909).

The Influence of the Temperature of Burning on the Rate of Hydration of Magnesium Oxide, E. DeM. Campbell, *J. Ind. Eng. Chem.*, **1,** 665 (1909).

The Types of Magnesite Deposits, K. A. Redlich, *Z. prakt. Geol.*, **17,** 300 (1909).

1910

Introduction of the Thomas Basic Steel Process in the U. S., Geo. W. Maynard, *Trans. Am. Inst. Mining Eng.*, **41,** 280 (1910).

Basic Refractories, Anon., *Met. Chem. Eng.*, **8,** 107 (1910).

The Raw Materials and Manufacture of Industrial Refractory Materials, Albert Granger, published by Ganthier-Villars (Paris-Leige), 1910.

Fuel and Refractory Materials, A. H. Sexton, published by Blackie (Edinburgh), 1910.

The Industrial Value of the Amorphous Magnesite of Kraubath, B. Grannig, *Oesterr. Z. Berg-Hüttenw.*, **59,** — (1910).

1911

Magnesite for Firebrick, Anon., *Brick Clay Record*, **38,** 532 (1911).

Further Data on Basic Converting, C. B. Neel, *Eng. Mining J.*, **91,** 964 (1911).

The Refractory Industry, P. Werner, published by A. Hartleben, Leipzig, 1911.

On Magnesite, G. Hörhager, *Stahl u. Eisen*, **31,** 355 (1911).

Bricks and Refractory Products Cemented by Spinel, K. A. Mankan, *Ceramique*, **14,** 172 (1911).

A Few Experiences with the 15 Ton Héroult Electric Furnace at South Chicago, C. G. Osborne, *Trans. Am. Electrochem. Soc.*, **19,** 207 (1911).

The Formation of Magnesite Deposits and their Association with Iron Ore Beds, J. Hörhager, *Oesterr. Z. Berg-Hüttenw.*, **59,** 222 (1911).

Works of the Austro-American Magnesite Company, Anon., *Iron Trade Rev.*, **48,** 111 (1911).

1912

The Making of Magnesite Crucibles, O. P. Watts, *Mining Sci.*, **66,** 413 (1912); *Wis. Eng.*, **17,** 64 (1913).

Refractories, F. A. J. Fitzgerald, *Met. Chem. Eng.*, **10,** 129 (1912); *Wis. Eng.*, **17,** 64 (1913).

Note on Spalling of Magnesia Brick, J. A. Thomas, *Eng. Mining J.*, **94,** 1018 (1912).

Note on Load Tests made on Magnesia, Chrome and Silica Bricks, G. H. Brown, *Trans. Am. Ceram. Soc.*, **14,** 391 (1912).

Magnesite and Its Technical Utilization, A. Kern, *Glückauf*, **48,** 271 (1912).

Dictionary of Applied Chemistry, Edward Thorpe, published by Longmans Green & Co., London, 1912.

Melting Points of Fire Bricks, C. W. Kanolt, *Technologic Paper*, **10,** U. S. Bureau of Standards; *J. Gas Lighting*, **119,** 503 (1913); *J. Franklin Inst.*, **174,** 225 (1912); *Trans. Am. Electrochem. Soc.*, **22,** 95 (1912).

The Production of Refractory Materials, G. Benfey, Hanover (1912).

A Study of the Open Hearth, published by Harbison Walker Refractories Co., Pittsburgh, Pa. (1912).

Refractories and Furnaces, F. T. Havard, published by McGraw-Hill Book Co. (1912).

Recent Developments in the Refractories Industry, F. T. Havard, *Trans. Am. Ceram. Soc.*, **14,** 480 (1912).

Genesis of the Pinolith Magnesite, Siderite and Ankerite of the Eastern Alps, K. Redlich, *Mineralog. petro. Mitt.*, **26,** 499 (1912).

The Electrical Resistivity of Firebrick at High Temperatures, A. Stansfield, D. L. MacLeod and J. W. McMahon, *Trans. Am. Electrochem. Soc.*, **22,** 89 (1912); *Met. Chem. Eng.*, **10,** 746 (1912).

Doelters Handbüch für Mineralchemie, Steinkopff Press (Dresden-Leipzig) (1912); Magnesite, H. Leitmeier, p. 220; Formation and Occurrence of Magnesite, K. A. Redlich, p. 243; Utilization of Magnesite, K. A. Redlich, p. 253; The Hydrate of Magnesium Carbonate, H. Leitmeier and G. d'Achiardi, p. 258.

1913

Refractory Bricks of Spinel, C. A. Mankan, *Ceramique*, **16,** 84 (1913).

Plants for Treating Dolomite for the Preparation of Basic Brick and Converter Linings, Anon., *Tonind.-Ztg.*, **37,** 936 (1913).

Development of Basic Lined Converter for Copper Mattes, E. W. Matthewson, *Trans. Am. Inst. Mining Eng.*, **46,** 469 (1913).

Testing and Judging Calcined Magnesite, A. Verwey, *Chem. Ztg.*, **37,** 813 (1913).

Thermal Dissociation of Amorphous Magnesite, O. Kallauner, *Chem. Ztg.*, **37,** 182 (1913); *Silikat.-Z.*, **1,** 165 (1913).

The Production of Magnesite in 1913, C. G. Yale and H. S. Gale, Mineral Resources of the U. S., 1913.

Refractories for Electric Furnaces, W. M. Johnson and G. N. Sieger, *Met. Chem. Eng.*, **11,** 645 (1913).

Refractories in the Iron and Steel Industry, H. W. Croft, *Iron Age*, **92,** 1163 (1913).

Magnesite Crucibles, D. M. Liddell, *Eng. Mining J.*, **96,** 503 (1913).

General Metallurgy, H. O. Hoffman, published by McGraw-Hill Book Co., 1913.

Thermal Dissociation of Amorphous Magnesite, O. Kallauner, *Chem. Ztg.*, **37,** 182 (1913).

Thermal Dissociation of Normal Dolomite, O. Kallauner, *Chem. Ztg.*, **37,** 1317 (1913).

1914

Effect of Steam upon Magnesite Brick or Calcined Magnesite, R. H. Youngman, *J. Ind. Eng. Chem.*, **6,** 1037 (1914); *Met. Chem. Eng.*, **12,** 620 (1914).

Refractory Brick, E. T. Montgomery, *Brick Clay Record*, **44,** 1144 (1914).

Basic Lined Converter Practice at Old Dominion Plant, L. C. Howard, *Trans. Am. Inst. Mining Eng.*, **46,** 476 (1914).

Thermal Dissociation of Normal Dolomite, O. Kallauner, *Chem. Ztg.*, **37,** 249 (1914).

Magnesite Deposits in Euboea, Greece, J. Hogg, *Trans. Inst. Mining Eng. (London)*, **46,** 128 (1914).

Occurrence, Preparation and Use of Magnesite, L. C. Morganroth, *Trans. Am. Inst. Mining Eng.*, **50,** 890 (1914).

Metallurgy of Copper, H. O. Hoffman, McGraw-Hill Book Co., New York, 1914.

The Testing of Clay Refractories with Special Reference to their Load Carrying Capacity at Furnace Temperatures, A. V. Bleininger and G. H. Brown, U. S. Bureau of Standards, *Technical Paper* No. **7**.

Magnesite, Editorial, *Mining Sci. Press*, **109,** 940 (1914).

The Metallurgy of Copper in the Basic Converter, B. de Saint Seine, *Rev. métal.*, **11,** 145 (1914).

The Specific Heat of Refractory Materials, W. Steger, *Silikat-Z.*, **1,** 22 (1913).

Tar Used in the Construction of Basic Linings in Steel Works, J. Wagner, *J. Iron Steel Inst.*, **2,** 283 (1914); *Rev. métal.*, **11,** 211 (1914).

Lining Basic Converters at Cananea, Anonymous, *Eng. Mining J.*, **97,** 809 (1914).

The Thermal Conductivity of Refractory Building Material, E. Heyn, *Stahl u. Eisen*, **34,** 832 (1914); *Chem. Zentr.*, **11,** 441 (1914).

Great Falls Converter Practice, A. E. Wheeler and M. W. Krejci, *Trans. Am. Inst. Mining Eng.*, **46,** 486 (1914).

Monolithic Magnetite Linings for Basic Copper Converters, A. E. Wheeler and M. W. Krejci, *Trans. Am. Inst. Mining Eng.*, **46,** 562 (1914).

The Binary System MgO–SiO_2, N. F. Bowen and O. Anderson, *Am. J. Sci.*, **37,** 487 (1914).

The Formation of Magnesite and Its Natural Occurrence, K. A. Redlich, *Fortschritte Mineral Krist. Petr.*, **42,** 49 (1914).

Late Developments of Magnesite Deposits in California and Nevada, H. S. Gale, *Bull.* **540,** U. S. Geol. Survey (1914).

Magnesite, Edward K. Judd, *Mineral Industry*, **22,** 483 (1913–1914).

An Austrian Magnesite Property Developed by American Capital, Anon., *Iron Trade Rev.*, **55,** 772 (1914).

1915

Magnesite Deposits and Possibilities in California, S. H. Dolbear, *Mining Press*, **110,** 105 (1915).

Reaction between Graphite and Magnesia, O. L. Kowalke and D. S. Grenfell, *Trans. Am. Electrochem. Soc.*, **27,** 221 (1915); *Met. Chem. Eng.*, **13,** 316 (1915).

Discoveries of Minerals in Styria and Lower Austria, A. Sigmund, *Neve. Jahrb. Min. Geol.*, **3,** 88 (1915).

Magnesite Deposits in British Columbia, R. E. Mansfield, Commerce Reports, pp. 177, 517 (1915); *British Clay Worker*, **23,** 279 (1915).

Solubility of Magnesium Carbonate in Natural Waters, K. C. Wells, *J. Am. Chem. Soc.*, **37,** 1704 (1915).

Solubility Product Constants of Calcium and Magnesium Carbonates, J. Johnston, *J. Am. Chem. Soc.*, **37,** 2001 (1915).

Magnesite Bricks, Anon., *Brit. Clay Worker*, **24,** 161 (1915).

Double Salts of Calcium Magnesium Carbonate, K. Schmidt, *Neues. Jahrb. Mineral Geol.*, **3,** 169 (1915).

On the Fusion and Volatilization of Our Most Refractory Oxides in the Electric Vacuum Furnace, Ruff, Seiferheld and Suda, *Z. anorg. Chem.*, **82,** 373 (1915); *Silikat-Z.*, **1,** 22 (1915).

The Thermal Conductivity of Refractory Materials, P. Goerens and J. W. Gilles, *Ferrum*, **12,** 1 (1915).

The Thermal Conductivity of Refractories, Boyd Dudley, *Trans. Am. Electrochem. Soc.*, **27,** 285 (1915).

Conductivity of Refractory Materials, G. Dougill, H. J. Hodsman and J. W. Cobb, *J. Soc. Chem. Ind.*, **34,** 465 (1915).

A. B. C. of Iron and Steel, published by Penton Publishing Co., 1915, 1919; Manufacture of Open Hearth Steel, K. Seaver, Electric Steel, F. T. Snyder.

1916

New Points on the Origin of Dolomite, F. M. Van Tuyl, *Am. J. Sci.*, **42,** 249 (1916).

The Basic Lined Converter in the Southwest, L. O. Howard, *Trans. Am. Inst. Mining Eng.*, **55,** 823 (1916).

Smelting at the Arizona Copper Co.'s Works, F. M. Flynn, *Trans. Am. Inst. Mining Eng.*, **55,** 805 (1916).

Sonoma Magnesite Mines, California, L. H. Eddy, *Eng. Mining J.*, **102,** 225 (1916).

An Immense Deposit of Magnesite in Southern Nevada, Anon., *Mining Eng. World*, **44,** 482 (1916).

Formation and Decomposition Temperatures of the Carbonates of Strontium, Barium, Calcium, and Magnesium, G. A. Hedvall, *Z. anorg. allgem. Chem.*, **98,** 47 (1916).

The Ternary System CaO, Al_2O_3, MgO, J. A. Rankin and H. E. Merwin *J. Am. Chem. Soc.*, **38,** 568 (1916).

A Sedimentary Magnesite Deposit, L. A. Palmer, *Eng. Mining J.*, **102,** 965 (1916).

Deterioration of Refractory Materials with Special Reference to Open Hearth Practice, H. B. Cronshaw, *Trans. Iron Steel Inst.*, **7,** 172 (1916).

The Common Refractory Oxides, Robert Sosman, *J. Ind. Eng. Chem.*, **8,** 985 (1916).

1917

Latent Heats of Fusion of Lime and Magnesia, E. W. Washburn, *Trans. Am. Ceram. Soc.*, **19,** 195 (1917).

Magnesite Deposits in Washington, Anonymous, *Iron Age*, **99,** 711 (1917).

Magnesite Furnace Lining, Anonymous, *Eng. Mining J.*, **104,** 53 (1917).

The Origin and Geochemistry of Magnesite, S. H. Dolbear, *Mining Sci. Press*, **114,** 237 (1917).

Spalling of Magnesite Bricks, J. W. Mellor, *Trans. Ceram. Soc. (Eng.)*, **16,** 85 (1917); *Eng. Mining J.*, **104,** 229 (1917).

Production of Magnesite by Years, 1887–1917, F. Hamilton, Cal. State Mining Bureau, *Bull.* **83** (1917).

Magnesite Deposits of Grenville District, Quebec, M. E. Wilson, *Trans. Am. Ceram. Soc.*, **19,** 254 (1917); Memoir 98, Canadian Geological Survey (1917).

A Curious Mineral in Magnesia Brick, H. B. Cronshaw, *Trans. Ceram. Soc. (Eng.)*, **16,** 101 (1917).

Properties of Magnesia Refractories, Le Chatelier and Bogitch, *Compt. rend.*, **165,** 448 (1917).

Refractory Magnesia, R. C. Gosrow, *Met. Chem. Eng.*, **17,** 415 (1917); *Eng. Mining J.*, **104,** 1132 (1917).

The Thermal Conductivity of Materials Employed in Furnace Construction, E. Griffiths, *Trans. Faraday Soc.*, **12,** 193 (1917).

Refractory Materials, Alfred Searles, Chas. Griffin & Co., London, 1917.

Crushing Strengths of Magnesite and Chrome Bricks at High Temperatures, Le Chatelier and Bogitch, *Compt. rend.*, **165,** 488 (1917); *J. Am. Ceram. Soc.*, **2,** 669 (1919).

Magnesite Production in 1915, Anonymous, *Iron Trade Rev.*, **60,** 471 (1917).

California Magnesite, Anonymous, *Iron Age*, **99,** 845 (1917).

Magnesite Brick Works at Baltimore, Anonymous, *Iron Trade Rev.*, **61,** 196 (1917).

Magnesite in Washington, Anonymous, *Eng. Mining J.*, **103,** 641 (1917).

Washington Magnesite Industry, C. D. Hudson, *Eng. Mining J.*, **104,** 549 (1917).

Magnesite on the Pacific Coast, Anonymous, *Mining Sci. Press*, **115**, 203 (1917).

Preparation of Pure Iron for Magnetic Purposes. T. D. Yensen, *Trans. Am. Electrochem. Soc.*, **32**, 176 (1917).

1918

Magnesite and Magnesite Brick, W. Donald, *Engineering*, **105**, 455 (1918); *Trans. Ceram. Soc. (Eng.)*, **17**, 486 (1918).

Notes on the Sintering of Magnesia, J. B. Ferguson, *J. Am. Ceram. Soc.*, **1**, 439 (1918).

Notes on the Possible Origin of Magnesite near Valley, Wash., O. D. Jenkins, *Econ. Geol.*, **13**, 381 (1918).

Magnesite Deposits of Washington, R. W. Stone, *Eng. Mining J.*, **105**, 665 (1918); *Iron Trade Rev.*, **62**, 1051 (1918).

Note on the Microstructure of Magnesite Bricks, Alexander Scott, *Trans. Ceram. Soc. (Eng.)*, **17**, 475 (1918).

Effect of Load on the Refractoriness of Firebricks, J. W. Mellor and W. Emory, *Trans. Ceram. Soc. (Eng.)*, **17**, 475 (1918); *Gas Journal*, **142**, 478 (1918).

Magnesite as Raw Material for Refractories, T. Crook, *J. Soc. Chem. Ind.*, **37**, 696 (1918).

Magnesia Ware, T. D. Yensen, *J. Am. Ceram. Soc.*, **1**, 730 (1918).

The Refractory Properties of Magnesia, Le Chatelier and Bogitch, *Trans. Ceram. Soc. (Eng.)*, **17**, 181 (1918).

Thermal Conductivity of Refractory Materials at High Temperatures, W. V. Rissum, *Z. Ver. deut. Ing.*, **62**, 601 (1918); *Chem. Zentr.*, **90**, 94 (1919).

The Ternary System MgO–Al_2O_3–SiO_2, G. A. Rankin and H. E. Merwin, *Am. J. Sci.*, **45**, 301 (1918).

Influence of the Temperature of Burning on the Rate of Hydration of Magnesium Oxide, E. de Mille Campbell, *J. Ind. Eng. Chem.*, **10**, 595 (1918).

Magnesite, Anonymous, *Sci. Am.*, **85**, 359 (1918).

Magnesite in Stevens County, Washington, Anonymous, *Concrete*, **12**, Suppl. 9 (1918).

Magnesite in 1917, Anonymous, *Eng. Mining J.*, **105**, 111 (1918).

Magnesite in the First Half of 1918, R. W. Stone, *Eng. Mining J.*, **106**, 564 (1918).

Crushing Strengths of MgO-SiO_2 Mixtures at High Temperatures, O. L. Kowalke and O. A. Hougen, *Trans. Am. Electrochem. Soc.*, **33**, 215 (1918).

Mining and Calcining Magnesite in Napa, Cal., Anon., *Mining Sci. Press*, **117**, 459 (1918).

Smelting Methods of El Paso, C. DeKalb, *Mining Sci. Press*, **116**, 711 (1918).

1919

Magnesite Industry in 1918, Anon., *Eng. Mining J.*, **107**, 131 (1919).

Basic Refractories for the Open Hearth, J. Spotts McDowell and R. M. Howe, *Trans. Am. Inst. Mining Eng.*, **55**, 291 (1919); *Blast Furnace and Steel*

Plant, **7**, 96 (1919); *Eng. Mining J.*, **107**, 648 (1919); *Clay Worker*, **72**, 223 (1919).

Experiments in Dead-Burning Dolomite, H. G. Schurecht, *J. Am. Ceram. Soc.*, **2**, 291 (1919).

Magnesite Industry in the United States, W. C. Phalen, *Mining Sci. Press*, **119**, 295 (1919).

Magnesite, Its Geology. Products and Their Uses, C. D. Dolman, *Bull. Am. Inst. Mining Eng.*, **152**, 1193 (1919).

The Ternary System CaO–MgO–SiO_2, Ferguson and Merwin, *Am. J. Sci.*, **48**, 81 (1919) (Series IV).

Magnesite in Washington, Anonymous, *Mining Sci. Press*, **119**, 57 (1919).

Magnesite—Its Occurrence and Uses, T. Crooks, *Mining Magazine*, **20**, 115 (1919).

Magnesite in Greece, Anonymous, *Eng. Mining J.*, **107**, 4 (1919).

Some American Dolomites, B. B. Read, *Chem. News*, **118**, 181 (1919).

CLASSIFICATION OF CLAYS ON A CERAMIC BASIS

By Arthur S. Watts

The classifications of clays in use at the present time are a source of confusion to most of us, owing to the lack of any definite lines of division between the different groups.

Controversy is constantly arising as to the definition of a kaolin. Does it cease to be a kaolin when it is removed from its place of occurrence and is washed free of its associated minerals? If not, why should a kaolin washed by human devices be still a kaolin, while a material from the same mineral source and washed by nature in a manner almost identical with the artificial process cease to be a kaolin.

Dr. Heinrich Ries suggests[1] that the word "kaolin" be used in referring to "white burning clays of residual character, which are composed mostly of silica, alumina and chemically combined water and have a very low content of fluxing impurities, especially iron." He observes that in this country kaolin is formed chiefly by weathering of pegmatites, and in rarer instances from feldspathic quartzites, limestone and talcose schists while in Europe they are probably in most cases products of weathered granite and quartz porphyry. The term "kaolin" refers by this definition only to those residual clays burning white and containing low flux content. By this definition portions of our American kaolin deposits which do not burn white are not kaolins.

Similar type of controversy arises in connection with the term "ball clay." Ries,[2] who has given this matter much careful consideration, includes under this term all "white burning plastic clays of sedimentary character which are extensively used as a necessary ingredient of whiteware mixtures in order to give the body sufficient plasticity and bonding power. They must, therefore, contain little or no iron oxide and possess good plasticity and tensile strength." He places no refractory limit,

[1] "Clays, Occurrence, Properties and Uses," p. 200.

[2] *Ibid.*, pp. 203–4.

observes that some ball clays require washing before being marketed and also notes that Missouri ball clays are residual. The term is developed from the use to which certain clays are applied, and is extremely vague. For example, the term "white burning" as applied to kaolins cannot be the same as when applied to ball clays, although the expression is the same.

The term "fire-clay" is even more vague than either "kaolin" or "ball clay." Ries[1] says that the term "properly speaking, refers to those clays capable of withstanding a high degree of heat." He laments its misuse and observes that in the absence of standards of refractoriness the term is frequently misapplied. He suggests that the term should be applied only to clays fusing above cone 27, and that it does not signify the presence of any other property except refractoriness. According to this definition the term "fire-clay" includes most kaolins and many ball clays. In most American literature the term "fire-clay" is understood to refer to a "coal measure clay" regardless of its refractoriness.

The Proposed Classification

This confusion in technical literature will continue until a classification is introduced based on the ceramic properties of the clays. Such a classification would not presume to so identify a clay that it could be duplicated. It would not attempt to physically classify clays in the sense that a chemical analysis indicates the chemical composition. It would, however, give the reader a general understanding of the physical behavior of the clay so that no serious results could come from limited substitution.

The ceramic classification could be based on not to exceed five properties, *viz.:* color, shrinkage, bonding strength, vitrification and fusion. The last two properties could, if desired, be combined under the term "refractoriness" but in the writer's judgment this would distinctly weaken the system. They must, however, be jointly considered for a proper classification of any clay.

Color need only be classified sufficiently to subdivide those shades closely related to white. The use of the four terms white, cream, buff and tan are sufficiently distinct in the minds of most

[1] "Clays, Occurrence, Properties and Uses," p. 205.

people so that only in a limited number of cases would confusion occur. Beyond this classification the use of distinct colors, as red, brown, and so forth, could be used.

Shrinkage should be subdivided into drying and total shrinkage. These are normally understood to refer to the decrease in linear dimension from the plastic state to the bone dry state and from the plastic state to some definite burned state. The shrinkage at cone 10 is very commonly used in advertising potter's clays and it is sufficiently high to indicate any abnormal flux content. The term "plastic state" is generally understood to signify that normal water content which will enable the mass to be molded into smooth, sharp edged shapes. The determination of volume shrinkages is recognized as more accurate than linear shrinkages; but the shrinkage of a horizontal face is within the necessary limits for general classification, which is all that is here proposed. Both drying and total shrinkage should be expressed in per cent of the original volume.

Primary kaolins, flint fire-clays and sandy clays generally have a drying shrinkage of 3 to 5 per cent. Plastic fire clays and secondary white clays have a drying shrinkage between 5 and 8 per cent. Ball clays and very plastic shales have a drying shrinkage between 8 and 12 per cent and in extreme cases as high as 15 per cent.

On being burned to cone 10 the primary kaolins generally show a total shrinkage of from 9 to 12 per cent, the flint fire clays generally have a total shrinkage of 6 to 10 per cent, the secondary white clays have a shrinkage of 10 to 14 per cent and the ball clays have a shrinkage of 16 to 18 per cent.

It would appear practical, therefore, to subdivide the drying shrinkage of clays into five classes, *i. e.*, less than 3 per cent, 3 to 6 per cent, 6 to 9 per cent, 9 to 12 per cent, and more than 12 per cent. The total shrinkage at cone 10 could likewise be subdivided into those less than 4 per cent, 4 to 8 per cent, 8 to 12 per cent, 12 to 16 per cent and more than 16 per cent.

Bonding Strength.—Bonding strength should be determined with a mixture of equal parts by weight of clay and standard Ottawa sand. Bleininger and Schurecht[1] used a grog of calcined

[1] U. S. Bureau of Standards, *Bull.* **79**.

flint fire-clay of the following sizes: 50 per cent between 20 and 60 mesh; 25 per cent between 60 and 150 mesh and 25 per cent through 150 mesh. They suggest the advisability of using a standard sand instead of this grog. Our Standards Committee suggest the use of standard silica sand between 20 and 28-mesh size in amount equal by weight to the clay.

The effect on the shrinkage of the blending of equal amounts of clay and sand is generally a reduction in drying and total shrinkage of about 40 per cent, provided the mass does not vitrify.

The transverse test has been found so much more satisfactory than any other means of determining the strength of the clay that the modulus of rupture as determined by this test and described in the Report of the Committee on Standards, 1919, pp. 40 to 43 inclusive, is recommenedd for this purpose. The same determination on a mixture of 50 per cent, by weight, clay and 50 per cent, by weight, non plastic (potter's flint recommended) gives a very reliable and satisfactory means of indicating the bonding strength of the clay.

The modulus of rupture for clays of high bonding power may be as high as 800 lbs. per sq. in. the white-burning secondary clays have values around 200 lbs., and the primary kaolins have values between 50 and 100 lbs. per sq. in. It would be practical, therefore, to divide clays on the basis of bonding power as follows:

Modulus of Rupture of 50 per cent Clay-50 per cent Flint Mixtures

(1) Those having a modulus of 800 lbs. per sq. in. or more—High
(2) Those having a modulus of 400–800 lbs. per sq. in.—Medium high
(3) Those having a modulus of 200–400 lbs. per sq. in.—Medium
(4) Those having a modulus of 100–200 lbs. per sq. in.—Medium low
(5) Those having a modulus of less than 100 lbs. per sq. in.—Low

Vitrification.—This term is understood as referring to that state in which the clay shows no absorption. This determination is difficult with most clays. If, however, the absorption is determined on the clay when burned at two or more temperatures, the temperature at which it becomes non-absorbent can generally be estimated with reasonable accuracy by extrapolation. For best results at least one burn should be made at cone 10 or above.

Fusion.—This determination is explained under "Softening Point Determination"—Report of Committee on Standards, 1918, pp. 44 to 46, inclusive.

Vitrification and fusion data are to be expressed in Seger-Orton pyrometric cones. They may be divided as follows:

(1) Vitrification occurs at cone 30 or above.
(2) Vitrification occurs above cone 25 and below cone 30.
(3) Vitrification occurs above cone 15 and below cone 25.
(4) Vitrification occurs above cone 5 and below cone 15.
(5) Vitrification occurs below cone 5.

Summary

The entire classification can be made on the following chart:

CLAY CLASSIFICATION

Date..... Shipper..... Location.....

Color: White, Cream, Buff, Tan.

	Low	Medium low	Medium	Medium high	High
Shrinkage—drying.....	0–3%	3–6%	6–9%	9–12%	above 12%
Shrinkage total, cone 10..	0–4%	4–8%	8–12%	12–16%	above 16%
Bonding strength, modulus of rupture, 50 per cent clay—50 per cent standard sand.....	0 to 100 lbs.	100 to 200 lbs.	200 to 400 lbs.	400 to 800 lbs.	Above 800 lbs.
Vitrification expressed in Orton cones.....	Below cone 5	Cone 5 to 15	Cone 15 to 25	Cone 25 to 30	Above cone 30
Fusion expressed in Orton cones.....	Below cone 5	Cone 5 to 15	Cone 15 to 25	Cone 25 to 30	Above cone 30

The report on physical properties would be general enough so that the errors due to irregular sampling, variation of deposit with increased exposure, and so forth, would not cause danger of industrial error. If desired, the terms, low, medium low, medium, medium high and high could be used in reporting on the different properties, and in practically all cases would meet the requirements of the trade as well or better than more specific data on material not representative of the entire deposit.

THE ELECTRIC CLEANING OF METALS FOR ENAMELING PURPOSES

By W. C. Lindemann

The enameling industry during the past few years has made radical changes in certain phases of the work, but probably the greatest changes have been, first, in the elimination of the old scaling process for removing grease with the substitution of chemical cleaning[1] and, second, in the use of new pickling agents to replace the old method of acid pickling. Certain individuals have advocated also the adoption of the electric method of removing grease, as practiced by electroplaters, to the cleaning of metals for enameling purposes.

The A. J. Lindemann & Hoverson Company for the past seven months has met with marked success in the application of the cleaning methods used in its electroplating department to its enameling process. This company is engaged in the enameling of sheet steel and cast iron in connection with stove manufacture.

Cleaning of Steel

A general description of the cleaning and pickling process is as follows: The metal in black shapes, as it comes from the presses, is immersed in an electric cleaning bath. The cleaning tank, which has a capacity of about 800 gallons, is made of metal and is connected to the positive pole of the generator. The solution is made of eight ounces of Wyandotte Metal Cleaner per gallon of water, and is maintained at the boiling temperature by the use of steam coils. Other cleaning agents have been used in place of the Wyandotte Cleaner and have given equally satisfactory results. Among these are Oakite Platers' Cleaner and Ajax Metal Cleaner.

The ware is suspended in the bath by means of metal hooks, hung from a bar which is used as the negative pole of the current. The current used is six volts direct current taken from a plating

[1] R. R. Danielson, "Cleaning of Sheet Steel for Enameling Purposes," *J. Am. Cer. Soc.*, **2**, 883 (1919).

generator. The current flowing depends upon the amount of material put into the tank at one time, the density averaging about four amperes per square foot of metal surface being cleaned. The ware is left in this tank for from one to two minutes, although if left longer—as much as ten to fifteen minutes—no harm is done to the metal, but the current is wasted in unnecessary work. Saving in time is one of the recognized advantages of the electric method of cleaning. Ware under similar conditions but without the use of the current would require from twenty to forty minutes for proper removal of grease and oil.

After the electric cleaning, the ware is rinsed in clean, warm water and is then taken immediately to the pickling tank. The pickling solution is made of Cleanrite No. 2 in the proportion of five ounces of Cleanrite to each gallon of water. When not using Cleanrite, a three per cent solution of sulphuric acid is used, which also gives very satisfactory results. The solution in either case is kept at a temperature of 150° to 160° F, and the ware remains in the bath from five to fifteen minutes, depending on the condition of the metal.

After being pickled, the ware is given a rinsing in luke-warm water and then in two cold-water baths. A final rinsing is given in a neutralizing bath, composed of one-half ounce of Alkali Special to each gallon of water. This material is composed of approximately two parts of caustic soda and one part of soda ash and is more effective than the ordinary neutralizing bath consisting of a weak solution of soda ash, although the latter may be used. The ware is allowed to remain in the bath, which is kept at boiling temperature, a sufficient length of time to thoroughly heat it. This causes it to dry very quickly when placed in the steam-coil dryer. This completes the process of preparing the sheet steel for enameling, about two tons of ware being handled each day.

Cleaning of Cast Iron

The methods for cleaning the cast-iron ware are very similar to that for steel, the electric method as described above being used for removing any oils or grease. Following the cleaning the cast iron is rinsed and then pickled in an 8 per cent solu-

tion of hydrofluoric acid. The pickling bath is kept at temperatures of 150° to 180° F, and the ware remains in the bath for approximately fifteen minutes.

After the pickling, the castings are rinsed in lukewarm water, then in cold water, and finally in a boiling solution of borax. This borax solution is made of four ounces of borax per gallon of water. The borax serves two purposes, as a neutralizing agent for the hydrofluoric acid and to give a protective covering on the castings to prevent them from becoming oxidized or becoming dirty from finger marks. This protective coating is especially necessary if the castings are allowed to stand for any length of time before being enameled.

Conclusions

The results obtained with the electric process of cleaning have clearly demonstrated the advantages over the older scaling or burning-off method. Stated briefly, these advantages are: (1) Lower cleaning costs; (2) saving in time with corresponding greater output; (3) elimination of oxide sludge; (4) elimination of the sponging or scrubbing of ware, to remove the deposit of carbon formed during scaling.

The success of the electric method of cleaning has suggested the application of electricity to pickling. Experiments have shown that the ware so handled is put into better condition for enameling, but the process entails extra cost beyond the gain in condition of the metal.

Discussion

MR. JAEGER: In this method of pickling, do you have any trouble with blistering of steel?

MR. LINDEMANN: Many people use muriatic acid instead of sulphuric acid for pickling with good results, and some probably use stronger solutions than we do. We formerly used a sulphuric acid solution, ranging from 5 to 6 per cent, but reduced this to 3 per cent in accordance with a paper by Treischel in this JOURNAL on the effect of acid on blistering of steel.[1] We had consid-

[1] Chester Treischel, "The Cause and Control of Blistering in Sheet-steel Enameling," *J. Am. Ceram. Soc.*, **2**, 774 (1918).

erable blistering with the 6 per cent acid solution but have practically eliminated it by the use of a 3 per cent solution. We have used different grades of steel during this time, and this may also account for the decrease in blistering; but we feel satisfied that the weaker solution has helped to control this trouble, and at the same time has resulted in a saving in acid with no appreciable difference in the time required for pickling.

THE TESTING OF CLAYS FOR CONCRETE AGGREGATE[1]

By D. H. Fuller

During the war, Mr. W. D. Richardson, of Columbus, Ohio, then with the Emergency Fleet Corporation, conducted a series of tests at this laboratory upon clays intended to produce, when fired, a light, vesicular mass, suitable for concrete aggregate. It is necessary that such clays be hard but overfired, containing a large volume of pore space so that fresh specimens will float in water. It is desirable also that the cavities be small and numerous rather than large and few. In fact, the more uniform the vesicular structure the more suitable it is for the purpose in view.

Material answering such requirements owing to its light weight and comparatively high strength when made up into concrete has certain possibilities for construction work where it is desirable to reduce the weight without proportionate loss in strength. It is evident that for this purpose shales and clays are most suitable, which produce the desired vesicular structure most readily, that is, overfire most easily. This pre-supposes the existence of a dense structure whether of the indurated or shale or the plastic clay type. The amount of carbon present is not a reliable criterion of the tendency to overfire as many very carbonaceous materials fail completely to produce the desired structure. It seems that the density of the clay structure, the amount and character of the carbon constituent and probably the presence of sulphates and sulphides are factors entering into the case.

It is not the purpose of this note to discuss the formation of the vesicular clay aggregate nor its manufacture on a commercial scale but to describe the method of testing materials for this purpose as practiced in the Pittsburgh laboratory. A large number of samples have been submitted for such tests and the simple

[1] By permission of the Director, Bureau of Standards

procedure might be of interest to other laboratories asked to do similar work.

From the exhaustive work of Mr. Richardson conducted on a large scale, it seems that rapid firing in rotary kilns represents the most feasible method of producing the aggregate. Hence to determine whether or not a clay or shale appears promising from this standpoint it need only be subjected to quick firing under heavily reducing conditions.

The method practiced in this laboratory consists in grinding the material, if a shale, through the 30-mesh sieve, followed by pugging to the condition of optimum plasticity, or by merely tempering the clay sample. Two-inch cubes are then molded by hand, then dried at room temperature and finally at 60° C. The specimens are next fired in a test kiln, heated by means of Fletcher burners, using natural gas and compressed air. The temperature of the furnace, as indicated by a protected thermo-couple, is raised according to the following heating schedule, under reducing conditions:

Time, minutes	Temperature, C°	Time, minutes	Temperature, C°
0	...	210	1030
30	150	240	1075
60	300	270	1150
90	450	300	1225
120	600	330	1300
150	750	360	1375
180	900		

It is necessary to provide openings for observing the outline of several of the cubes during the firing and for removing two specimens every 30 minutes after the temperature of 900° has been reached. These must be preserved for examination. In case decided bloating is observed at any one point specimens may be removed at shorter intervals, say 20 minutes. Upon the appearance of evidence of fusion the firing is, of course, stopped. Upon the completion of the run the gas is turned off and the furnace allowed to cool naturally.

The specimens are then examined to note the degree of bloating and tested by observing whether or not they float in water. By preparing several salt solutions (NaCl) between the specific gravities

of 1 to 1.1 the apparent density of the pieces can be quickly determined. The temperature at which bloating begins is to be noted as well as the point at which the most desirable structure is produced, which is determined by the floating behavior and the appearance upon breaking the specimen. The formation of a fine and uniform cellular structure is to be preferred to one consisting of large and irregular cavities. Materials which fail to float in the salt solution of specific gravity 1.1 or which consist of large cavities enclosed by a shell of dense, vitrified clay are not considered suitable for the purpose.

ACTIVITIES OF THE SOCIETY

The Story of the Twenty-second Annual Meeting

The influence of the Twenty-second Annual Meeting of the American Ceramic Society, which opened at the Bellevue-Stratford, Philadelphia, on February 23rd, will long be felt by those who were there. The opinion was generally expressed that the meeting was the best the Society had ever known.

A meeting of the Board of Trustees was called on Sunday afternoon at 2 o'clock. With the exception of Mr. Beecher, who was detained at home by illness, every member of the Board, together with the Secretary and the Assistant Secretary, was present. The usual routine business was transacted and the report was approved for submission to the Society. This report will be printed in the *Year Book*, so that it will suffice to say that it was of an optimistic nature and pointed out that the Society has experienced a year of unprecedented success. The financial position is secure and the membership is increasing. A second session of the Board was held on Sunday evening.

The Society as a whole met in the "Rose Garden" on Monday morning. There was a large attendance and more than the usual interest. Several members who had often been present in the early days but who had been missed recently now appeared and were warmly greeted. Langenbeck, somewhat grayer than of old, but his very self; Stover, who had been reported about ready for flowers, renewing his youth and energy; Burt, not quite so much of an absentee yet in nearly the same class, were among those present. Of the other presidents of the first decade there were Charles F. Binns, F. W. Walker, and A. V. Bleininger.

The president, R. T. Stull, opened the first session and delivered the annual address which was a plea for improved mechanical science in the manufacture of brick. He pointed out that 70 per cent of the cost of brick manufacture was in fuel and labor and that, while continuous kilns were strongly advocated for the saving of fuel, little had been done for the saving of labor.

The report of the Board of Trustees and the reports of Standing Committees were read and will be duly published. Mr. Minton, for the Committee on Papers and Program, made an interesting analysis of the gradually increased length of the program of the annual meeting and the percentage of members who contribute to it. The facts as shown are that in the early years of the Society about fifteen per cent of the members wrote papers; the last year has shown only three per cent. The recent rapid growth in membership is, of course, the immediate cause of this, but there is undoubtedly a tendency on the part of many members to "Let George do it," "George," in this case, occupying a settee, part of which is located in the colleges and part in the government bureaus.

A special committee had been appointed last year to formulate a definition of the word "Ceramic." Dr. E. W. Washburn, the chairman of this committee, was ready with the report which revealed excellent and painstaking work. The origin of the word was traced through Greek to Sanscrit, in which ancient tongue it had the significance of a substance developed by the aid of fire. Thus does primitive usage justify the interpretation which modern ceramists have placed upon their craft.

The afternoon of Monday saw the opening of the technical program. Certain papers of general interest were selected for presentation at this session but the main program was subdivided so that each of the Industrial Divisions might have its own group of papers. Consequently there were five simultaneous meetings on Tuesday and the work was rapidly disposed of.

On Monday night there was an innovation in the form of a Smoker and Section Q. This was held in the Clover Room and was attended by about 250 members and friends. There were singing and moving pictures but the stunt of the evening was pulled off by Professor J. B. Shaw and a number of Alfred students, who produced an original sketch entitled, "A Day in the Secretary's Office." Professor Shaw himself represented the Assistant Secretary, W. H. Reid, the Secretary, George Blumenthal, Jr., the office boy, and Messrs. Kenyon, Lobaugh, Collin, and Sherwood, four members who called at the office to make

complaints. Parodies of popular songs had been written and were given with much gusto.

On Tuesday night the banquet was held and was attended by nearly 160 persons. Round tables for twelve or eight had been provided and the members arranged themselves in congenial groups. F. W. Walker acted as toastmaster in his usual happy manner. Before calling on the speakers Mr. Walker indulged in some reminiscences of the early days and spoke of the men who, having founded the Society, carried it on until it was able to run alone.

The first speaker was Mr. Cattell, of Philadelphia, who delighted the audience with his eloquence and racy wit. He was succeeded by Professor Althouse, who delivered an address filled with inspiring thought and illustrated by humorous anecdotes. The toastmaster then called upon former presidents Bleininger and Purdy, each of whom had words of value for the Society.

Wednesday morning had been set apart for a discussion on continuous kilns. This proved most attractive and the session was largely attended. So enthusiastic was the spirit that the meeting re-convened in the afternoon and adjourned only to leave time for the closing business session. The scrutineers of election announced the new officers: R. H. Minton, president; E. T. Montgomery, vice-president; R. K. Hursh, treasurer; and F. H. Riddle, trustee.

Thursday was devoted to sight-seeing. The local committee had with admirable energy and organization arranged trips in automobiles to industrial plants and other places of interest around the city. In the morning a party visited the Baldwin Locomotive Works and the O. W. Ketcham Terra Cotta Works, while a second group went to the plants of the Abrasive Company, the Philadelphia Textile Machinery Company, the Conkling-Armstrong Terra Cotta Company, and the Brown Instrument Company. In the afternoon some went to the Hog Island shipbuilding yards, and others visited points of historical interest and the Victor Talking Machine Company at Camden. An interesting trip was arranged on Wednesday afternoon for the ladies who attended the convention.

Too high praise cannot be given to the local committee, of which Frederick Stanger was chairman. A multitude of details had been worked out, and each event of the week passed off smoothly and enjoyably. Such efficiency removed untold burdens from the shoulders of the officers, and it is largely due to the efforts of the committee that the meeting was so marked a success.

CHAS. F. BINNS

Necrology

J. T. BRAMLETT.—Julian Troutman Bramlett, dealer in fireclays, died of influenza pneumonia, complicated by meningitis on Feb. 27, 1920, at his home in Tallahatchie County, Miss.

Mr. Bramlett, who, until some four years prior to his death, was engaged in the drug business at Oxford, Miss., was born in 1881, and was educated in the school at Oxford, the University of Mississippi and the Louisville (Ky.) College of Pharmacy.

The property on which Mr. Bramlett's clay was located had been in the family for several generations, being a part of the estate of John Troutman, grandfather of Mr. Bramlett. No attempt had ever been made to put this clay on the market until 1916, when the European war created a demand for domestic clays. Mr. Bramlett, seeing the possibilities of development in the clay business, moved his family to Tallahatchie County and engaged in the business of mining clay. He was a member of both the American Ceramic Society and the National Brick Manufacturers' Association. He is survived by his wife, two small daughters, mother, father, two sisters and two brothers.

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The Value of Fuel Saved in One Year

¶ Actual records were kept for 365 days of the burning of 9-inch, high-grade, refractory brick in one continuous tunnel kiln and in seven 30-foot round kilns, during which time 5,110,000 brick were burned in the tunnel kiln as against 5,040,000 in the seven round kilns.

¶ But this isn't all—the actual labor saving amounted to $5,808.00. Taking into consideration the necessary items of depreciation, interest on plant, maintenance and repairs, the average yearly cost for burning 1,000 brick in the continuous tunnel kiln system was $2.95 as against $6.20 in the round kilns.

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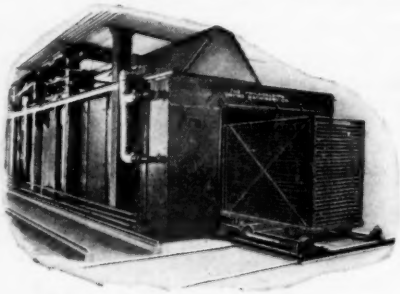

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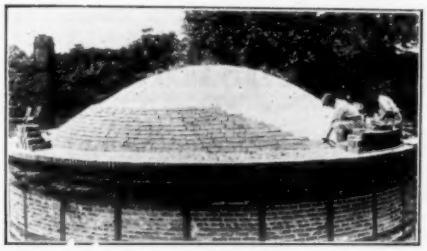
Third:—This kiln allows an absolute and positive control of the firing zone, and in the firing zone a reducing or oxidizing condition can be maintained at will.

Fourth:—The cooling of the ware as well as the water-smoking and pre-heating in this kiln are absolutely automatic. It is impossible to get the receiving end of the tunnel too hot.

Fifth:—This kiln will save about 50% on labor and from 65% to 75% on fuel as compared with periodic kilns. Burning time is cut down by ⅓ to ½. Where saggers are used, they will last twice as long.

Carl H. Zwermann — Robinson, Ill.



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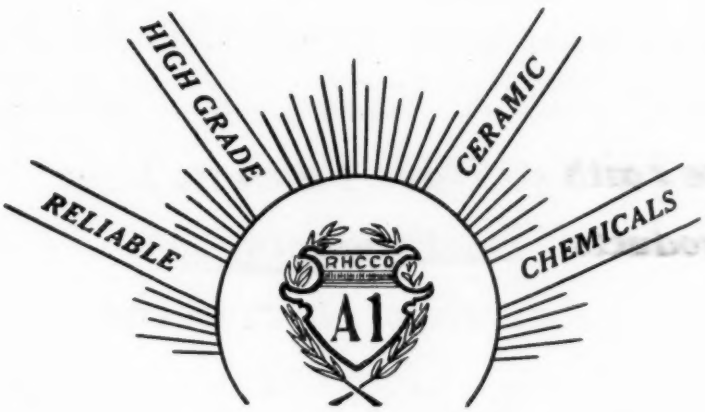

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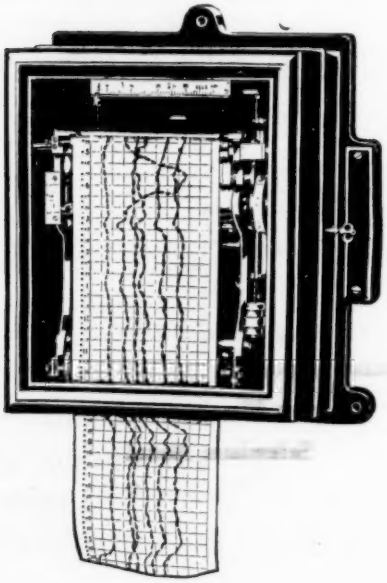

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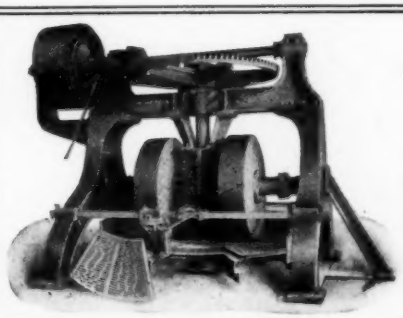

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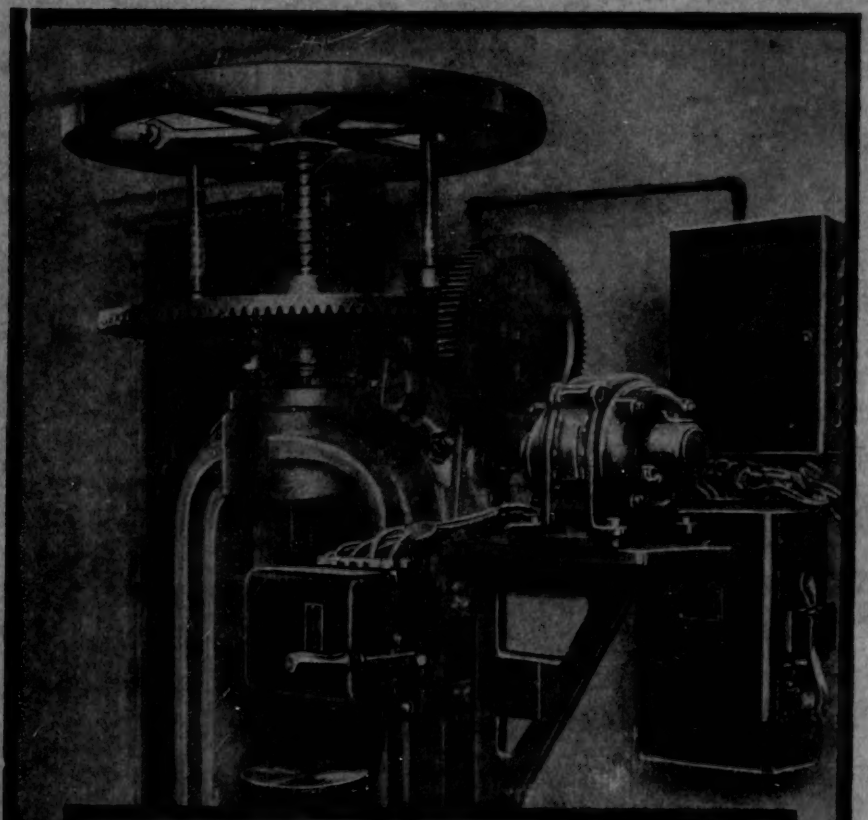

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